PCM CARRIER FOR RURAL TELEPHONE SYSTEMS

PURPOSE: The purpose of this addendum is to provide interim recommendations concerning the application of PCM span line transfer systems in small exchange cables. A review of these potential problem areas might be helpful in solving some existing problems with PCM span line transfer systems.

ADDITION: APPENDIX IV

INTERIM RECOMMENDATIONS FOR PCM SPAN LINE DESIGN

1. GENERAL

1.1 PCM spare span switches provide a means of transferring traffic to another line when the span line carrying this traffic fails. When properly selected and applied, they offer a means of increasing the reliability of T1 carrier systems. The purpose of this appendix is to outline some problems and considerations in the application of these systems.

1.2 The material in this appendix refers to 1:N switches, where 1 spare line is used to protect N main or working lines. While 1:1 switches (1 main line and 1 spare), which only switch at the end detecting fault, can overcome some of the problems encountered, their use is probably limited to routes where only one ultimate system is planned by economic considerations.

2. APPLICATION CONSIDERATIONS AND POTENTIAL PROBLEM AREAS

2.1 The switching element in a spare span switching system may be either a relay or a seminconductor switch. If the switching element is a relay, there is a relatively long interval (5-50 milliseconds) during the switching process, where the traffic signal is not applied to either the main or the spare line. This is the interval during which the relay physically moves between contacts. If precautions are not taken, this can lead to failure to complete the transfer when applied to cables which have poor near end crosstalk characteristics. The design of a relay type switch must include some provision to have the spare line energized at all times so that the repeaters on the line will remain stable. Semiconductor type switches, which exhibit very short switching times, are not subject to this problem.

2.11 Early T1 repeaters required fixed LBO's to build-out the cable loss to about 32 dB. Currently, all manufacturers provide automatic line build-out (ALBO) in repeaters. These ALBO repeaters depend on the incoming pulses to maintain proper gain. An absence of incoming pulses may cause the repeater to provide full gain very quickly. If the repeaters are allowed to go to full gain, crosstalk from other systems may be sufficient to cause errors at the repeater output. This depends mainly on the near-end crosstalk loss of the pairs used and the maximum gain of the repeater. Some present repeaters have gains of 36 dB or more. If the repeaters go to full gain during the span switching process, the errors thus generated may cause the line receiving the transfer to look bad -- and the transfer to be inhibited. Depending on which pair combinations are bad, the system may fail to restore.

2.12 This condition cannot arise with the faster, semiconductor type switches because during switching the driving signal is not removed for a sufficent time to allow the repeater gain to change. It cannot arise in 1 for 1 systems which only switch at the end detecting fault because the driving signal is not removed from the line at all. In slower relay type switches, certain precautions must be taken in the design of the switch to avoid these problems. Several possible solutions are listed below. In selecting relay type switches, care should be taken to insure that one or more of these features are present. They are:

1. Insuring that the time required to detect a fault condition (often called the Burst Protection Time) is longer than the duration of errors caused by the relay switching.

2. Insuring that once a decision is made to transfer (or restore), the error detection circuitry on the line receiving the transfer (or restoral) is disabled for a interval long enough to allow transfer (or restoral) to proceed to conclusion irrespective of line condition.

3. Electronically applying a substitute signal to the line during the time the relay is switching.

Application of a relay switching system utilizing one of the above techniques should result in satisfactory operation.

2.13 The technique of short spacing repeaters is not effective when switching problems are caused by poor NEXT because, in the absence of an input signal, the repeater goes to full gain. Short spacing the repeaters limits repeater gain to the loss of the preceding section only when an input signal is present.

2.2 The AT&T "T1 Outstate Automatic Protection Switching Requirements" is widely accepted. but there is no universal standard at this time. As a general statement, a span line transfer system by one manufacturer is not compatible with that of another manufacturer. Decisions or "commands" to

transfer to a spare span line or return to the main line vary somewhat. In some cases, pulses are removed to force the transfer. In others, error patterns or digital signals are utilized.

2.3 In order to provide protection to span lines along a route which terminate in different offices, several configurations are possible:

1. Terminal-to-terminal operation. In this configuration a distinct spare span line is required to each office where a system is terminated. This configuration requires the least switching equipment but the most span line equipment. (See Exhibit 1).

2. Sectional or span switching operation. This configuration utilizes 1 spare line and switching equipment at all intermediate offices. If the main span line fails between 2 offices, the traffic on this system is transferred to the spare line only between these 2 offices. The remainder of the spare line at other points along the route is still available to protect against failures in other systems or other failures of the same system. (See Exhibit 2). Generally, to be used in this type of application, a switch must remove errors generated in one section before the signal is allowed to pass to an adjacent section. This is done so that a fault in one section does not cause transfer in other sections. Further, the switch must insert a substitute signal (usually called a keep alive signal) in the event of channel bank failure so that this condition does not cause transfer to the spare.

3. Since span or sectional switching requires a large amount of span switching equipment, some manufacturers offer a system which utilizes only one spare while still incorporating switch units at the channel bank locations only. (See Exhibit 3). Termed quasi-sectional or quasi-span switching, this system has several unique features:

   a. Only one system at a time can transfer.

   b. More than 1 spare line is needed on routes that branch.

   c. Priority may not be freely assignable between the systems.

These units allow for cost savings while providing a somewhat lower level of protection.

2.4 Older repeaters which do not contain automatic LBO's may go into oscillation when no signal is applied. In this mode, the output pulses are longer than those found in a normal T1 signal. If these repeaters are in use, care should be taken to insure that the span switch used will detect these long pulses and transfer.

2.5 In determining whether or not a span line is in a fault condition, the switching system compares the number of errors occurring on a line in a given time with a predetermined threshold. If this threshold is exceeded, the line is determined to be in fault and transfer to the spare is initiated. On some switching systems this threshold is variable, on others it is fixed. In specifying a switching system, consideration should be given to the type of traffic the span lines will be carrying. While 10^{-4} (1 error in 10,000 pulses) is sufficient for voice circuits, 10^{-5}, 10^{-6}, or 10^{-7} may be required where data transmission is required.

2.6 The various span switching systems vary greatly in their philosophy on automatic restoral (automatically returning traffic from the spare to its main line, if that line becomes good).

2.61 Some switches do not provide this restoral feature. Maintenance personnel must restore the line manually. Some switches can be manually restored from a remote location. In selecting a transfer switch, the inconvenience and cost of manually restoring a system must be weighed against the added cost of an automatic restoral system. In manual restoral systems, if a second line fails before the first failed line is restored, a service outage will result, even though there may be enough good lines to carry all the traffic. While the probability of simultaneous, unrelated equipment failures is very small, simultaneous failures may result from lightning or the activity of workmen. Further, these failures may be of an intermittent nature that makes automatic restoral more attractive.

2.62 Another factor to be considered is the time required to determine a made good condition prior to automatic restoral. Here also, there are two philosophies: (1) Restore as quickly as is practical to free the spare line for subsequent failure; and (2) Require the line to be good for a longer time prior to reset to insure that the line is good. In cases where high rates of simultaneous failure are suspected, consideration should be given to faster restoring switches.

2.7 Some spare span switches are offered without priority systems in their standard form. Priority may be included as an option. In order to prevent unintended cross connections between channel banks, it is recommended that all switch installations have a priority arrangement.

3. INTERIM RECOMMENDATIONS

3.1 Often two telephone companies are involved in T carrier applications. Any recommendations on span line transfer systems must necessarily

consider that mutually acceptable agreements must be made with the connecting company. While connecting company requirements may be very specific in some applications, standardization on one type of system for the entire industry has not been accomplished. Thus, universal end-to-end compatibility is not now practical. Lacking this, interim recommendations are offered including some alternatives.

3.2 Outside Plant: Since many of the potential span transfer problems involve NEXT, outside plant is the first consideration. If new cable is planned, use only filled cable to maintain long term stability of cable parameters. Screen type cable should be specified if the cable layup does not contain nonadjacent units. (See Exhibit 4). Screen type cable may not be more economical than the added short spaced repeaters in many applications, but the improvement in NEXT could significantly improve the overall system operation. Separate cables or screen type cables offer the ultimate in NEXT between directions to achieve maximum repeater spacing. If the two-cable operation is chosen, repeaters should still be wired for bi-directional operation. The use of unidirectional repeaters requires two spare lines to maintain service.

3.21 Select cable pairs for maximum NEXT isolation between transmit and receive pairs. Where possible these should be located in nonadjacent units or at least separate units. For cables with no separate units (small cables of layer type construction) within the core, determine the cable layup. (This information is available from the cable manufacturer.) Pairs should be selected to maximize the physical separation between the transmit and receive pairs. Adjacent pairs with nearly equal twist lengths can have especially poor NEXT.

3.3 Span Transfer Systems: First of all, make sure that a span line transfer system is required. Weigh the alternatives and their costs.

3.31 For a one PCM trunk carrier system, consider adding a second terminal (shelf and common equipment) instead of a span line transfer system. Divide the traffic between systems to maintain partial service during equipment failure periods. This, of course, would have to be discussed with the connecting company.

3.32 For two or more trunk systems, consider manual patching to the spare span line to restore service.

3.33 If automatic span line transfer is considered essential, consider the features of the proposed switch and the cable condition together in specifying the switch. If cable conditions are less than ideal, high speed switching or slower switches utilizing some techniques of paragraph 2.12 are indicated. Consider whether manual, remote or automatic restoral is appropriate based on office location and cost considerations.

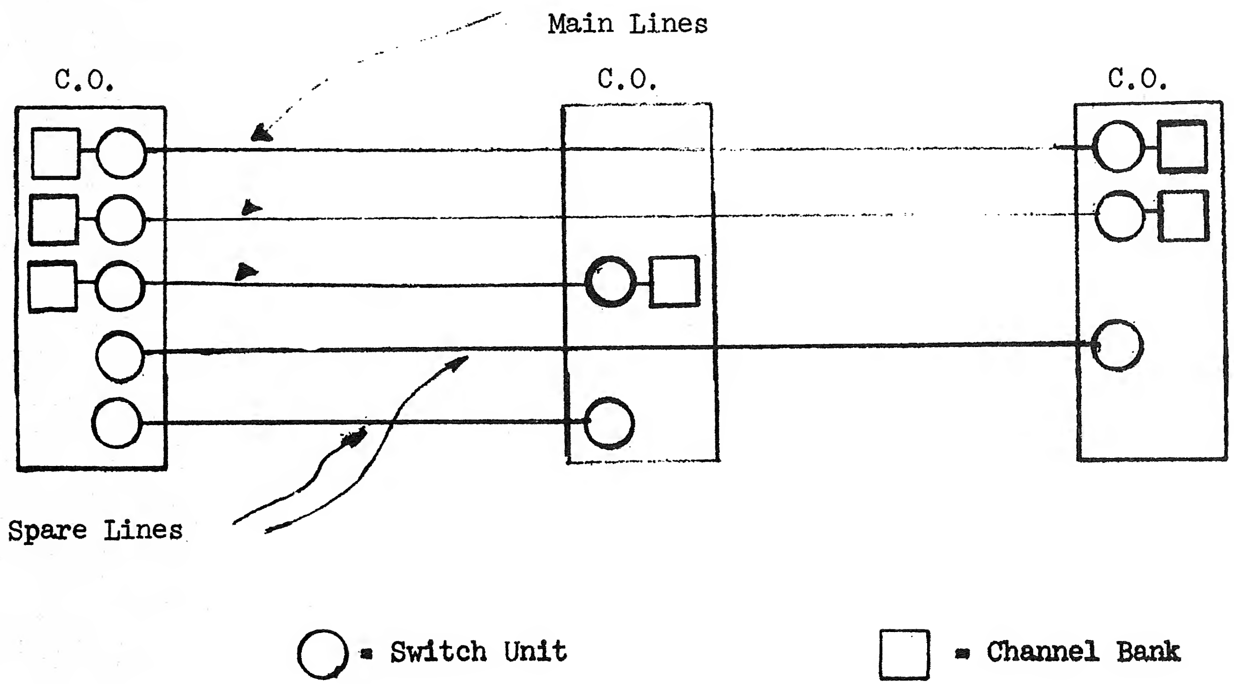
3.34 The manufacturer making the best proposal on terminal or span line equipment may not manufacture an appropriate span line transfer system. Therefore, it is recommended that span transfer system quotations be separated from other quotations. Review and understand the manufacturers' proposals before making a selection. There may be minor conflicts in the area of interface; before making the final decisions, discuss the proposed types of interface equipment with each proposed manufactuer. Obtain written assurances on the overall application from each manufacturer, including any special interface considerations.

3.4 Specification Guidelines: Refer to Exhibit 5 for guidelines in specifying span line transfer parameters. Exhibit 5 is only a partial list of desired span line transfer characteristics aimed specifically at reducing potential application problems. Add to this list additional items as necessary.

3.5 PCM Subscriber Carrier: The preceding recommendations are aimed primarily at PCM trunk carrier systems. Existing small size cables of questionable electrical parameters are even more likely to be proposed for PCM subscriber carrier applications. The considerations affecting subscriber circuit outage are slightly different from trunk circuit considerations. Weigh the alternatives based on individual system needs. Factors in this decision include how large a geographic area is affected and how quickly the telephone company can respond to system alarms. Because of potential moisture problems with existing air core cables, PCM subscriber carrier should generally be limited to filled cable applications using screen type cables.

EXHIBIT 1

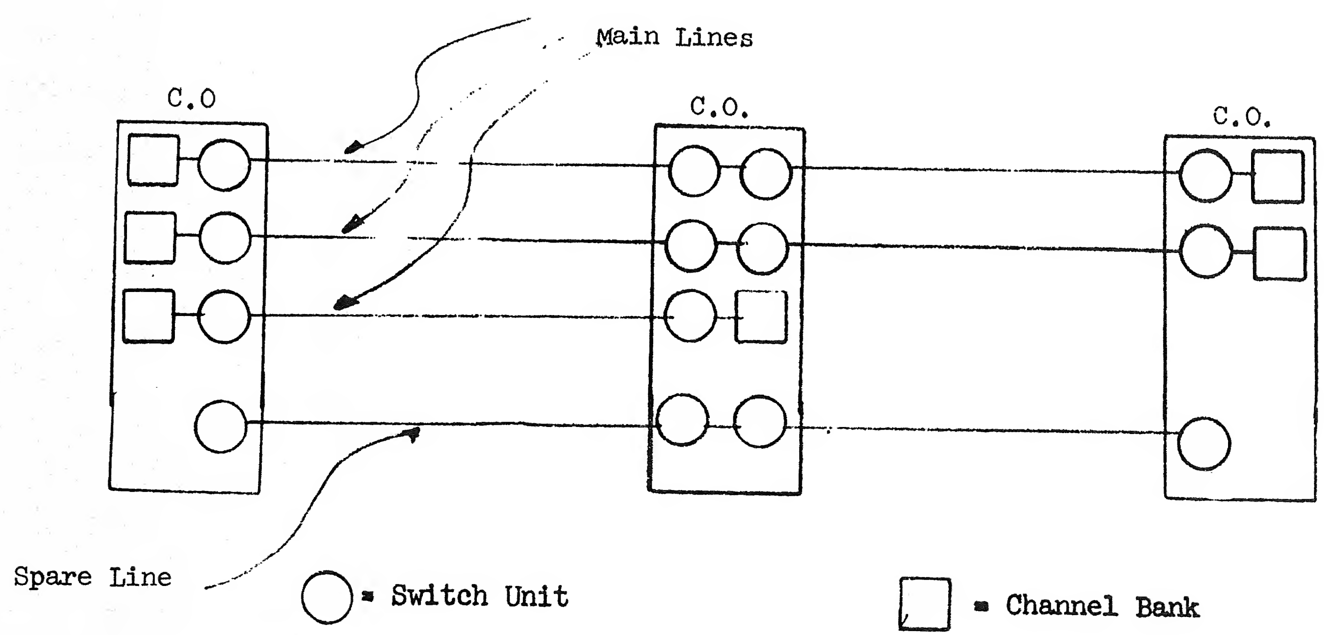
Terminal-to-Terminal Switching System



Separate spare line is required between all offices which has systems between them.

EXHIBIT 2

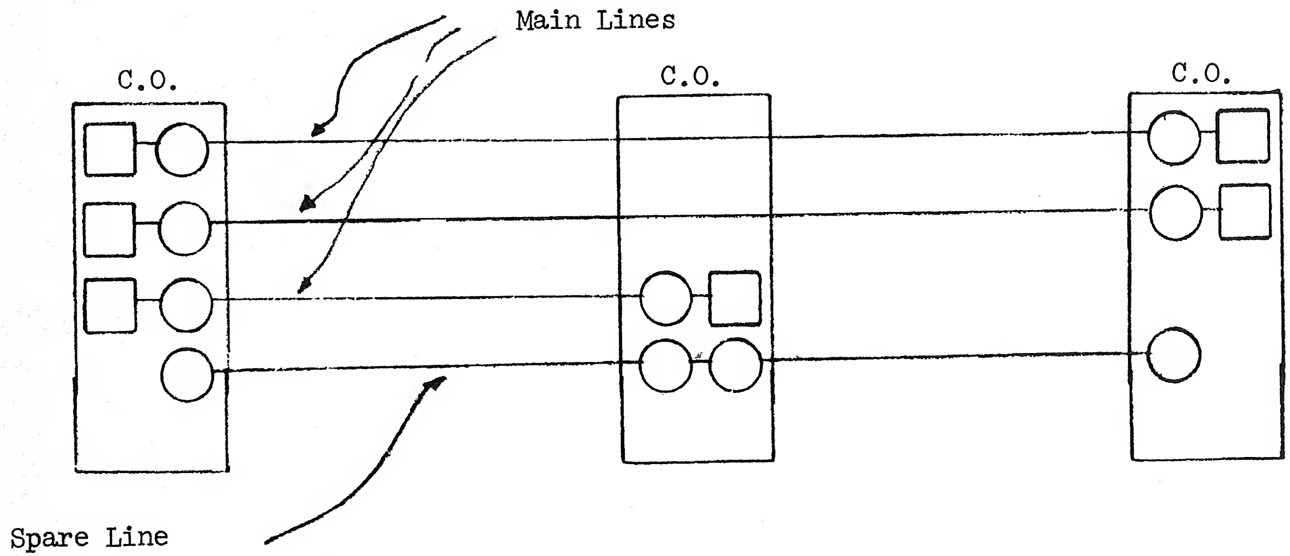
Sectional Switching System



Switch units are required on all span lines in all offices. A thru span line requires back-to-back switch units.

EXHIBIT 3

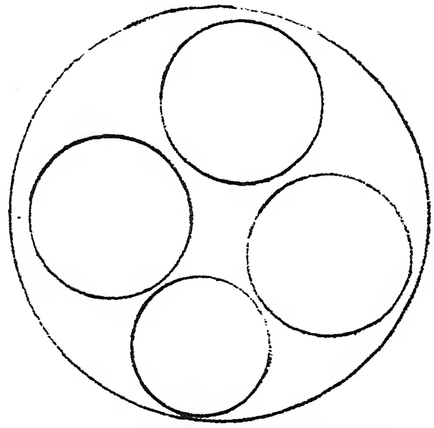
<u>Quasi-Span Switching System</u>



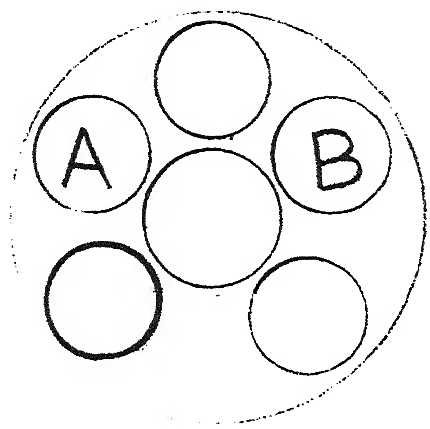
= Switch Unit   = channel banks.

Switch units required only at channel banks. Only 1 spare line is used. Only 1 main line can transfer at a time.

EXHIBIT 4



All units are adjacent. Screen type cable should be used in preference to this cable.



Units A and B are nonadjacent. This cable configuration generally has higher crosstalk isolation between A and B. Screen cable is not essential unless number of anticipated systems is greater than the number of pairs in one outer units. For larger cables, install screen if the number of pairs required is greater than those available in non-adjacent units.

EXHIBIT 5

Specification Guidelines for
Span Transfer Systems

NOTE: The following are some minimum suggested guidelines for specifying span line transfer systems. This list is not complete, but can aid in reducing potential application problems. This list may be added to Form 397b or 397c when span switches are specified.

1. INTERFACE: Standard T1 PCM at all ports. (3V peak, bipolar, 1.544 Mbs, 100 ohms, balanced.)

2. ULTIMATE CAPACITY:

☐ 1 for 1 protection, only one direction of transmission is switched.

☐ 1 for N protection, N = ___________

3. ERRORS: Switch must monitor:

☐ Bipolar violations and loss of signal

☐ Long pulses, bipolar violations and loss of signal

4. ERROR RATES: Switches must be capable of any of the following thresholds:

☐ 10^{-4}

☐ 10^{-5}

☐ 10^{-6}

☐ 10^{-7}

5. BURST PROTECTION: Must not transfer on 5 ms burst of errors

☐ Fixed ☐ Strapable

6. SWITCHING TIME:

☐ Switching time of less than 100 microseconds is required. (Recommended for small cables with poor NEXT characteristics.)

EXHIBIT 5 - (Continued)

/__/ Slower relay type switches are acceptable.

/__/ Other. Specify: ______________________________

7. ERROR REMOVAL:

/__/ Terminal-to-Terminal Operation.

/__/ Sectional Operation.

(Error removal and keep alive signals are required.)

/__/ Quasi-Sectional Operation.

8. AUTOMATIC RESTORAL:

/__/ Automatic restoral is required.

/__/ Automatic restoral is not required.

9. PRIORITY: It shall be possible to alter the established priority without extensive rewiring.

Method of priority alteration: (Jackfield, switches, etc.)

____

____

10. SPAN SIGNAL CONDITION:

/__/ The main and spare line shall have pulses applied at all times (except during switching) irrespective of terminal condition.

/__/ Absence of pulses on the line during switching should not exceed 100 microseconds.

1. ALARMS AND STATUS:

Systems must provide relay closure for office alarms in event of

/__/ Transfer /__/ Failure to transfer

Other Requirements: ______________________________

____

____

EXHIBIT 5 - (Continued)

12. REMOTE LOOPING

/ / Transfer equipment provides remote looping of an interrogation signal.

/ / Remote looping is not required.

PCM CARRIER FOR RURAL TELEPHONE SYSTEMS

CONTENTS

GENERAL

1 This section provides a survey and some Application Engineering Considerations for Pulse Code Modulation, PCM, carrier equipment ilable for use in rural telephone systems for trunk and subscriber vice. PCM carrier equipment has decreased in cost over the past five rs to the point that all telephone companies should consider its use never an expansion of trunk or subscriber facilities is required.

2 REA Forms 397b and 397c which are plans and specifications documents for trunk and subscriber carrier systems, respectively, should be d for the purchase of PCM carrier equipment. REA TE&CM 903, "Applica-n Guide for Subscriber Carrier Specifications," REA Form 397c and CM 904, "Application Guide for Trunk Carrier Specifications," REA Form b are available for assistance in using these forms.

3 Equipment Specifications for PCM Trunk Carrier Equipment are found in REA's PE-60 Specification which is distributed with REA Bulletin -50. Equipment Specifications for PCM Subscriber Carrier are found in 's PE-64 Specification which is distributed with REA Bulletin 345-66.

2. EQUIPMENT CHARACTERISTICS

2.1 The purpose of a telephone carrier system is to combine several telephone channels for transmission over a single transmission path. PCM carrier is a time division carrier system where time is divided into slots and a channel is assigned to each slot. The terminal equipment is the multiplexing apparatus which scans the input signals in rotation. In a 24 channel PCM carrier system, for example, the transmitter samples the telephone channel voice frequency amplitude and signaling state of each of the 24 channels sequentially, multiplexes the information on a time division basis and encodes the samples into a coded pulse train for transmission over the repeatered line. The receiver reconstructs the original amplitudes to a very close approximation, demultiplexes them together with the proper signaling states and distributes them to the corresponding channels. As indicated, all PCM carrier systems have a built in signaling system for trunk and subscriber signaling requirements.

2.2 The facility connecting two PCM terminals is called the span line for wire line PCM carrier systems. It consists of span terminating equipment and outside plant equipment which includes line repeaters and repeater housings. Power supply equipment for powering the outside mounted repeaters is located with the span terminating equipment, usually in a central office location. The repeaters which are located at periodic intervals along the wire line path regenerate the pulse stream. As indicated above, the coded information is transmitted by the presence or absence of pulses in specific time slots, therefore, the absence of a pulse is equally as important as the presence of one. The repeater, therefore, regenerates the pulses and preserves pulse blanks that appear at the input to the repeater. An inherent advantage of this type of repeater is that noise interference is not continually amplified at each repeater since the repeater regenerates a new pulse stream which is identical to the one transmitted by the terminal.

2.3 Most of the PCM carrier systems discussed in this survey are designed to be applied over telephone cable plant commonly found in service. In recent years, new cables have been designed especially for PCM carrier equipment. These cables segregate the pairs within a cable into two shielded compartments, thus completely separating the "transmit" and "receive" pairs.

2.4 PCM carrier can be applied to microwave radio. It may be transmitted over angular modulated microwave radio using a digital to analog multiplexer or it can modulate the radio using digital modulation techniques without the intervening multiplexer.

3. TYPES OF PCM CARRIER SYSTEMS

3.1 T1 24 Channel PCM Carrier System - The 24 channel T1 system is the most commonly used system today. It multiplexes 24 voice

channels at the terminal for transmission over regular cable plant. Since the system is designed to provide high quality voice frequency channels (300 to 3400 Hz), each channel must be sampled 8000 times a second. Each voice sample is encoded into a 7 or 8 bit code (depending on the terminal bank designation). Signaling information is added as an 8th bit, or else substituted for the 8th bit in some frames. After all channels are sampled, a synchronizing bit is added, thus each frame consists of 193 bits of information (24 channels X 8 bits + 1 framing bit). The bit rate thus is 8000 samples X 193 bits = 1,544,000 bits per second. The span line facilities, therefore, have to be able to regenerate a 1.544 megabit stream of pulses. Two cable pairs are required for each T1 carrier span line, one for each direction of transmission. The 24 channel T1 carrier system transmits bipolar pulses into the cable pairs, that is, succeeding pulses in the bit stream are of opposite polarity (of course, there may be blanks between the pulses). This basic system is used for both trunk and subscriber carrier systems. Figure 1 displays the pulse format for a T1 24 channel system.

3.2 T1 36 channel PCM Carrier Systems - A more recent carrier system multiplexes 36 voice channels at the terminal for transmission over two cable pairs using span facilities almost identical to those of the 24 channel system. The output of the terminal into the span is a ternary signal at a bit rate of 1.542 megabits. This span line bit rate is almost the same as the 1.544 megabit rate mentioned above and the regenerative repeaters used for a 36 channel system can also be used for 24 channel systems. A 24 channel PCM T1 repeater cannot, however, be used for a 36 channel carrier system. Nevertheless, because of the similarity of the span line bit stream and span line equipment, this 36 channel system is generally considered a T1 system.

In this system 36 channels are sampled in rotation and each sample is encoded into a 7 bit code (excluding signaling) which totals 252 bits of information (36 channels X 7 bits). After the 36th channel, a 37th channel using 5 bits is added to the frame for a total of 257 bits per frame. This 37th channel of 5 bits is used for synchronization of frames plus signaling functions on a time shared basis. Since each channel is sampled 8000 times a second (just as the 24 channel system) the total length of the bit stream is 2,056,000 bits/second (257 bits/frame X 8000 frames/second).

A code conversion now takes place in order to reduce the bit stream to 1.542 megabits/second for transmission over T1 span line facilities. This is done by feeding the 2.056 megabit stream into a 4/3 code converter. The bit stream is divided in groups of four bits and for each four bits a three bit signal (ternary coded output) actually goes out on the span line. The signal on the span line is not a strict bipolar signal as it is on the 24 channel system. There may now be consecutive positive or negative pulses. The bit stream is compatible with 24 channel bit streams on other pairs in a cable. In spite of the fact that the ternary signal on the cable pair has more power at station carrier frequencies (around 112 kHz) than the bipolar signal of 24 channel systems, the bit stream

is still pretty much compatible with station carrier equipment on other pairs in a cable. This basic system is used for subscriber carrier systems. Figure 2 is a display of the 36 channel pulse format and 4/3 encoder.

3.3 T2 Carrier System - The T2 is a digital transmission system designed to provide service economically over distances up to 500 miles. It is the second level of a developing hierarchy of digital transmission systems for the nationwide network. The first level being the T1 system described above.

The T2 has four times the capacity of the T1, 6.312 megabits/second. A T2 multiplex terminal, M12, combines the outputs of four T1 systems into the 6.312 megabit/second digital stream. The T2 can transmit over wire pairs in twisted pair cables, coaxial cables or microwave radio. Since the telephone cables generally in use today (average .083 µF/mile mutual capacitance of the wire pairs) have a very high attenuation and poor crosstalk properties at 6.312 megabits/second a cable especially designed for the T2 system is available. This cable contains wire pairs with a mutual capacitance of .039 µF/mile which results in the attenuation being about one-half of .083 µF/mile cables. Therefore, fewer repeaters are required.

4. CHANNEL TERMINAL BANKS FOR T1 CARRIER SYSTEMS

4.1 The D1 Channel Bank - The D1 channel bank provides for 24 trunk channels. Twenty-four channels are sampled in rotation and each channel sample is encoded into a 7 bit binary code. This code provides for up to 128 (2^7) different amplitude levels to which each sample can be encoded. Timing considerations preclude the use of code "0000000" so actually only 127 levels are used. An eighth bit added to the 7 bit code is used for signaling. Refer to Figure 1. The D1 channel bank is considered the first generation PCM carrier terminal.

4.11 The D1D Channel Bank - An existing D1 channel bank can be upgraded to match a D3 channel bank at the other end by replacing certain network cards and still retain some of the D1 parts including the pre-wired bays. The modified D1 then becomes the D1D channel bank. It is not anticipated at this writing there will be much demand for D1D channel banks in the REA Program.

4.2 The D2 Channel Bank - The D2 channel bank also provides for 24 channels. Twenty-four channels are sampled in rotation and each channel sample is encoded into an 8 bit binary code. This code provides for up to 256 (2^8) different amplitude levels to which each sample can be encoded. Timing considerations preclude the use of code "00000000" so actually only 255 levels are used. The signaling state of each channel is transmitted every sixth frame when the eighth (least significant) bit is borrowed for this purpose. Refer to Figure 1. As a result of using this format, the number of levels that are available for encoding is

double that of the D1 channel bank and the voice quality is improved. The D2 channel bank is considered the second generation PCM carrier terminal and will be used in the future for intertoll and PCM switching.

4.3 The D3 Channel Bank - The D3 channel bank provides for 24 channels and is identical in operation to the D2 channel bank described in Paragraph 4.2. There is one basic difference between the D2 and D3. The channel unit time slot assignments for the 24 channels in the D3 are changed from the assignments for the D2. To clarify the channel unit-time slot assignments of the D1, D2 and D3 channel banks the following is the channel assignments of the three banks.

Time Slots	D1	D2	D3
1	1	12	1
2	13	13	2
3	2	1	3
4	14	17	4
5	3	5	5
6	15	21	6
7	4	9	7
8	16	15	8
9	5	3	9
10	17	19	10
11	6	7	11
12	18	23	12
13	7	11	13
14	19	14	14
15	8	2	15
16	20	18	16
17	9	6	17
18	21	22	18
19	10	10	19
20	22	16	20
21	11	4	21
22	23	20	22
23	12	8	23
24	24	24	24

Depending on the manufacturer's approach to building the D3, there may be changes in the alarms and the physical size of the terminals. To make a D2 terminal compatible on an end to end basis with a D3 terminal it is necessary to provide a change in the wiring of the channel banks which is accomplished by providing another terminal cabinet or an adapter cable or a programmer connector to provide for the different channel assignment. All manufacturers' D2 alarm systems are compatible with D3 either by design or optional wiring changes. It is necessary, therefore, on an interconnect arrangement of carrier facilities with a connecting company that there be agreement on the type of channel bank terminals to be used.

event all 12 frequencies are used in the repeater span before specifying additional interrogation pair, etc., the office repeater would not have to be interrogated because in the event of a failure, interrogation of the adjacent repeater would refer to the suspected office repeater if it were defective. In fact, it is not mandatory to interrogate every repeater location as every other repeater could be interrogated; then one set of 12 frequencies could cover 24 repeaters equipped for interrogation. The system would still be helpful by being able to pinpoint trouble to within two repeater locations, then a portable error detector can be used to determine the performance of the repeater at the housing. The method is useful where cable pairs are at a premium on long systems requiring several interrogation pairs.

5. PCM SUBSCRIBER CARRIER SYSTEMS

5.1 Various subscriber carrier systems are available which are similar to the trunk carrier systems described in Paragraph 4. Systems providing 24, 36 or 96 subscriber circuits between a central office and a remote location are available. The span line equipment is identical for both trunk and subscriber systems (except for the 36 channel system as covered in Paragraph 3.2).

5.2 The subscriber terminal is designed to be placed inside a pole or pedestal mounted cabinet to which subscriber lines are connected for transmission back to the central office terminal over two cable pairs via a T1 span line. On high density applications, several subscriber terminals, together with protection, batteries and power supplies can be mounted inside a small building to accommodate many subscriber lines. When installed in a weatherproof cabinet the subscriber terminal requires ac power, 120 Vac to operate. Battery standby power is available in the event of an ac power failure. The central office terminal and office repeater of those subscriber systems are powered from the central office battery. The field mounted repeaters of the span line are usually powered from the central office and subscriber terminal locations.

5.3 The voice frequency drop limitation from the subscriber terminal is 1200 to 1500 ohms (depending on the manufacturer's recommendation) excluding the telephone set. It is recommended that the voice frequency extensions be designed so that the 1 kHz loss value of 8 dB maximum plus the central office loss is not exceeded to the furthermost subscriber location. The net loss of the carrier system is usually 2 dB leaving 6 dB for the voice frequency drop. Reference should be made to TE&CM Section 424 for more information on transmission losses of subscriber circuits.

5.4 PCM carrier systems can provide all the necessary signaling requirements for subscriber lines - ringing, on and off hook supervision and rotary or pushbutton dialing. Depending on the manufacturer's options, single-party, multiparty, paystation and PABX service can be offered. Rotary or pushbutton dialing from the telephone set will pass through the carrier system. On multiparty service all these systems can accommodate circle digit subscriber identification. Some manufacturers can provide two-party identification (ANI) with divided ringing or bridged frequency selective ringing.

5.5 Depending on the manufacturer's options, various types of service alarms are available (in addition to the carrier group alarm for system failures) such as ac power failure at the subscriber terminal, subscriber cabinet door open, power supply failure, etc. Also many innovations are becoming available with respect to providing automatic checks and alarm indications of individual channels and remote testing of the voice frequency drop at the subscriber terminal.

5.6 There is another type of PCM subscriber line carrier equipment which combines a 24 channel PCM carrier system with switching

techniques to provide 96 to 112 subscriber lines at a remote location from the central office. With this equipment, the subscriber lines are connected to one of the 24 trunks on demand. The span line is made up of a standard T1 line using two cable pairs. The 24 channel PCM carrier system is combined with the switching equipment as one unit of equipment at the central office and at the subscriber location in the field. In order to increase the traffic handling capacity of this system, intrasystem calls are set up with a link in the remote terminal. If such links are not provided, a "local" call would tie up two trunks back to the central office. No trunks are needed once the intrasystem call is set up. For equipment of this type, the span line termination, repeaters, power feed equipment is identical to that discussed in Paragraph 7.1. The field terminal is connected to subscriber lines that can be extended to about 1200 ohms excluding the telephone set. The field terminal requires local ac power and is equipped with battery standby in the event of failure of the ac power line.

5.61 Subscriber line equipment is available which performs the same functions as that described in 5.6 except that physical, PCM carrier or frequency division modulated trunks can be used. Equipment of this type, whether carrier or physical trunks are used back to the central office, has been labeled "Electronic Subscriber Line Systems."

6. SOME TERMINAL EQUIPMENT ENGINEERING CONSIDERATIONS

6.1 The terminal equipment installed in a central office (or in a cabinet for subscriber systems) contains the individual channel units (with required signaling and voice frequency terminations) and the common equipment for the systems - encoder (transmitter), decoder (receiver), power supply, alarms, terminal checkout systems, etc. For the procurement of terminal equipment, REA provides Form 397b, "Design Specifications for Wire Line Trunk Carrier Systems," and Form 397c, "Design Specifications for Subscriber Carrier Systems." If these guideline forms are properly used, the resulting plans and specifications for the system application should provide the necessary information to determine terminal equipment requirements for the intended application. Various miscellaneous items relating to terminal equipment are discussed here for additional information.

6.2 As previously discussed in Paragraphs 3.1 and 3.2, the 7 or 8 bit word contains the signaling state of each individual channel. For the application of a PCM carrier system from an unattended Class 5 central office to a Class 4 toll center, the built in signaling of the PCM carrier system should be used. It is unnecessary in most applications to use inband (2600 Hz) signaling systems over the PCM carrier for this application. Trunk carrier systems are available with all standard signaling and voice frequency termination options such as:

E&M signaling, 4 wire
E&M signaling, 2 wire
One way loop dial, originating
One way loop dial, terminating
Foreign exchange, central office
Foreign exchange, subscriber

PCM carrier system channel units for 2W E&M signaling come equipped with built in voice frequency hybrids complete with A&B leads. Therefore, there is no need to specify 4 wire channel units and external four wire term sets to be used with PCM carrier systems except for special applications.

6.21 In the D1 channel bank terminal, two possible separate signaling paths for each channel (in one direction of transmission) are possible through a PCM carrier system. Loop dial and E&M signaling only require one path. Other more complex signaling systems such as for foreign exchange signaling require two signaling paths simultaneously. Two schemes which accomplish this in D1 PCM carrier systems are called the D1A and D1B.

In the D1A, one bit of the eight bit word is set aside for signaling. The D1A arrangement borrows a second bit (the least significant one) to provide the second signaling path. The arrangement is generally satisfactory, however, in calls to an operator (where no charge is made for a call and no reverse battery supervision is sent back over the channel) there is some degradation to the quality of the voice transmission.

In the D1B, the signaling bit of the eight bit code in the first frame provides the first signaling path. The signaling bit of the second frame provides the second signaling path. The third and fourth frame signaling bits are inhibited. The process repeats every four frames. Thus, the type of signaling required, D1A or D1B, should be specified.

6.22 In the D2 channel bank terminal, two signaling paths are provided by having the signaling bit in every other sixth frame carry the information for one path while the same bit in alternate sixth frames carry the other signaling path. In the application of D2 it is unnecessary to specify the method of signaling.

7. SOME SPAN LINE EQUIPMENT ENGINEERING CONSIDERATIONS

7.1 The concept of the span line is to provide a transmission facility between two points for a high speed digital bit stream. Connected to this facility could be a trunk carrier system such as D1 type or D2 type terminal, subscriber line system, data system, etc. As a result the span terminating equipment mounted in a central office is considered separate from the channel bank equipment. The access arrangement for the span lines and terminals is such that any terminal may be patched to

any line. This allows a high degree of flexibility possible for quick rearrangement of equipment. The span line equipment may consist of:

Regenerative repeaters installed in the outside plant
Office mounted regenerative repeaters
PCM span line patch panel
Power supply for regenerative repeaters
Spare span line (which includes all of the above equipment)
Automatic switchover equipment for main and spare span line
Interrogation system for regenerative repeaters
Span line looping equipment
Order wire termination

7.11 The regenerative repeaters are mounted in the outside plant especially built repeater housings. The repeaters are powered from the central office span line power supply, from an intermediate point, or a subscriber terminal location.

7.12 Electrical protection of carrier equipment is covered in general in TE&CM 822, "Electrical Protection of Carrier Equipment," however, for PCM carrier an additional precaution is required. First, in order to reduce system down time, gas tube arresters are recommended for all protectors in the span line and at the main frame at the office. It is imperative that the holdover time of the gas tubes be as short as possible. This is usually controlled to some extent by the dc current flowing out of the repeater feed power supply during a short to ground condition when the gas tube or tubes are operated. In specifying the type of gas tube, its holdover characteristics should coordinate with the maximum amount of current that could flow from the repeater feed supply during a short condition. Gas tubes on the REA List of Materials have satisfactory holdover characteristics if the current is limited to around 200 mA during gas tube operation. If gas tubes holdover for an extended period of time the interruption to the PCM bit stream may cause a carrier system alarm. The Carrier Group Alarm sequence will disconnect all the circuits even though the system automatically restores at a later time.

7.13 PCM carrier repeaters can be protected by the "by-pass" arrangement of protectors where the protectors are not connected to earth ground at the repeater location (the repeater housing exposed to the public must be grounded to prevent personal shock hazard). TE&CM 822, "Electrical Protection of Carrier Equipment," explains this practice. In general, it should be left to the carrier manufacturer to recommend the protection practice to follow, however, if the telephone company experiences an unusual amount of carrier repeater failures due to lightning, power supply faults, etc., it should consider the "by-pass" arrangement. It is an REA requirement that all repeater housings have the capability of "by-pass" protection.

7.14 In spare span lines, the repeaters are actually powered and operating with a bit stream provided by another operating system

or a self-excited line driver. Thus, if the spare line develops a malfunction, it will go into an alarm condition indicating the need for servicing. This prevents patching to a non-functioning line in the event an operating system goes into alarm.

7.15 Most repeaters used today contain automatic equalization making it unnecessary to fit each repeater with line buildout networks, LBO's. The repeaters automatically regulate for line loss from 9 dB to about 35 dB at 772 kHz. Repeater spacing guidelines are outlined in Paragraph 8 of this TE&CM.

7.16 Power supply equipment is usually included as part of the span line terminating equipment. The repeaters are powered from the central office with various voltage combinations (depending on the length of the system) to provide from 60 mA to 140 mA (different values among manufacturers). Power is dc simplexed over one cable pair and looped back at a distant repeater point on the other cable pair of the span line. Usual voltage combinations are -50, -130, +130 volts dc which is derived from the -50 volts dc central office battery by a dc-dc converter. All power supply feeds should be current limited (both + and - power supplies) for proper operation of gas tube arrestors to minimize holdover delay after the tube fires.

7.2 Repeater housings can constitute a large investment as all sizes and types are available. Careful consideration should be given as to the ultimate number of span lines to be provided, including spare span lines. In general, it is recommended that at least one spare span line be installed along a route, even if there is only one operating system. If a working spare span line is available, it would not normally be necessary to shut down a system in order to maintain the repeaters.

7.3 Both pressurized and non-pressurized repeater housings are available from manufacturers. Obviously, if pressure is maintained in the cables, pressure should be maintained in the repeater housings. In most REA financed systems, however, pressure is not used. It is not recommended that a pressurized repeater housing be used without pressure. Unless the housing is vented, water will build up inside the housing due to condensation from the air and cyclic temperatures.

7.4 Mounted inside each repeater housing are one or more interrogation filters (and associated amplifiers) which are part of the interrogation system for determining location of faulty repeaters from the central office terminal. Refer to Appendix I for some considerations in laying out the interrogation system.

7.5 Automatic switchover equipment is usually included as part of the span line terminating equipment. The system will automatically switch the PCM terminal from a faulty span line to the spare span line without dropping the system. This will occur before the terminal alarm operates and the only alarm given is that of a span line failure.

7.6 Span line looping equipment is usually included as part of the span line terminating equipment. This is also part of the interrogation system. With it a span line is looped back at the distant office when the line is being interrogated. Thus, both directions of all repeaters may be interrogated from one office. Refer to Appendix I for considerations in specifying span line looping equipment.

7.7 In developing plans for the application of PCM carrier systems along a route, consideration should be taken of the total number of cable pairs required in the span line for all the requirements that could be specified.

2 pairs per PCM carrier system

2 pairs for spare span line

1 - 2 pairs or more for interrogation systems, depending on application (see Appendix I)

1 order wire pair

For the first system, as many as six or seven pairs may actually be required. Of course, for each additional system only two pairs are required per system since the spare line pairs, interrogation pairs and order wire pairs serve all systems normally required in rural system applications.

Measures can be taken to reduce the number of pairs required such as using the order wire pair as the interrogation pair also. (This can be done by a special jack access arrangement. This may be stated as a requirement in the plans and specifications.) Also it is unnecessary on long system applications to interrogate all repeater locations. Every second or third repeater could be interrogated and in such a manner reduce the need for additional interrogation pairs. Also, polarity sensitive interrogation filters can be specified to reduce the number of interrogation pairs. Refer to Appendix I. In making any cost computation or comparisons, the cost of the total number of cable pairs required, especially on one system applications, should be carefully considered.

8. REPEATER SPACING GUIDELINES

8.1 PCM carrier is designed to operate on conventional cable pairs in plant commonly found in a telephone exchange. In the REA Program this consists mostly of .083 μF/mile average mutual capacitance, plastic insulated cable pairs of 22 and 24 gauge. Very rarely is 19 gauge cable used. The cable plant should be in a good state of repair, be free of moisture, and possess satisfactory transmission characteristics at 772 kHz.

To attain maximum spacing of repeaters (that is, to eliminate near end crosstalk as a factor in determining maximum spacing) two cables can be used, one for each direction of transmission. Or, specially designed

cables which are constructed with two shielded compartments can be used to attain maximum repeater spacing. Many applications of PCM carrier, however, are on existing plant for operation of the carrier repeaters in one cable sheath.

8.2 The following is a simplified procedure for calculating repeater spacings:

8.21 For one cable operation determine near end crosstalk loss, (m-s value) for each different type of cable in the route. See Figure 3. Appendix II discusses the near end crosstalk characteristics of cables as expressed in Figure 3.

8.22 Determine the maximum repeater section loss for each value of m-s from Figure 4. Figure 4 accounts for the total number of systems to operate in one cable which affects the repeater spacing; the more systems in one cable, the shorter the repeater spacing. Therefore, it is necessary to carefully estimate the total number of systems which will operate in the one cable.

8.23 Calculate the corresponding repeater spacing from Figure 5 which gives the cable transmission loss at 55°F, 100°F and 140°F for polyethylene insulated cables. For buried cable applications use the values at 100°F. For aerial cable applications, use the values at 140°F.

8.24 Where several sizes and gauges of cable are encountered in any one repeater section, the lowest near-end crosstalk loss (m-s) value in that repeater section controls the section length.

8.25 Sections next to an exchange central office should have a loss of no greater than 23 dB to minimize interference from impulse noise generated in switching equipment. Likewise this section should be no less than 9 dB.

8.26 In actual practice most of the effort in laying out a span line should be directed at placing repeaters at locations which are accessible for maintenance, at load points, at existing pedestals and manholes, etc.

8.27 If two cables, or special compartment type cable is used, repeaters can be spaced to the maximum capability of the repeater without regard to near-end crosstalk limitation. The maximum section loss for repeaters is 33.5 dB. Compute the spacing using cable attenuation data at 100°F for buried cable and 140°F for aerial cable. The central office end sections should be no greater than 23 dB or less than 9 dB where other pairs in the same cable are used for voice frequency physical circuits. On dedicated cables for PCM carrier, the central office equipment end section can be a full section.

8.28 Figure 6 is an example of repeater spacing computations for three systems operating over a span line 10 miles long using existing buried cable plans consisting of a 25 pair, 22-gauge PIC cable.

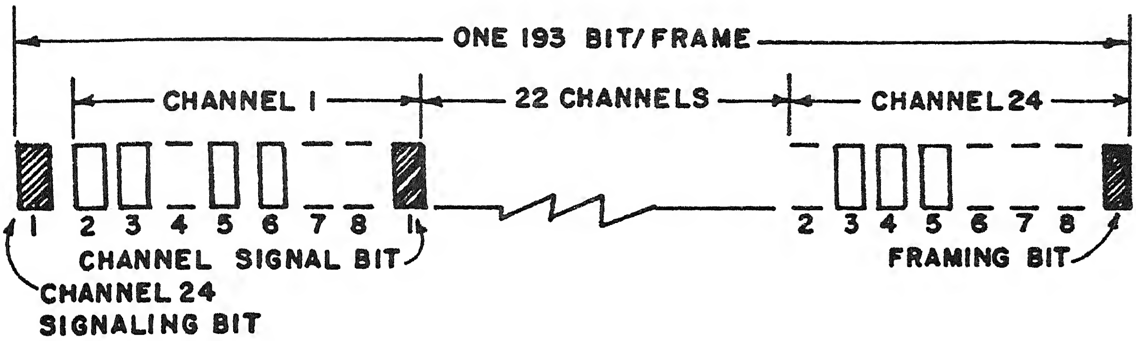
8.3 An improvement in the near-end coupling losses of paired cables has been achieved by the use of a special shielding which divides the cable pairs within a cable into two compartments.

Figure 7 describes the configuration of this type cable. As stated in Paragraph 8.27, it is unnecessary to space the repeaters closer together to compensate for the near-end coupling loss as is done in one cable operation. Appendix III discusses the near-end crosstalk improvements of this type cable.

Figure 8 is an application of repeaters to the same example of Figure 6 using grease filled compartment type cable designed for PCM carrier. It is seen here that two less repeaters are required.

8.4 Grease Filled Polyethylene Insulated Conductor Cable - To keep moisture out of cables, all the voids between conductors are filled with a special grease-like material to form a filling compound. A characteristic of this type cable is that for .083 μF/mile mutual capacitance between conductors, the attenuation at the higher carrier frequencies is less than for air filled. This can be noted by comparing the attenuation values for grease filled and air filled cables in Figure 5. Therefore, if a cable is provided with special shielding which divides the cable pairs into two shielded compartments to improve the near-end crosstalk isolation and if the cable is also grease filled which protects the cable from water permeation and as a bonus has less loss at 772 kHz frequencies, this type facility becomes an ideal facility for PCM carrier. This type cable facility is recommended for PCM carrier where new outside plant is provided for the PCM carrier equipment.

T 1 CARRIER
D1 CHANNEL BANK FORMAT



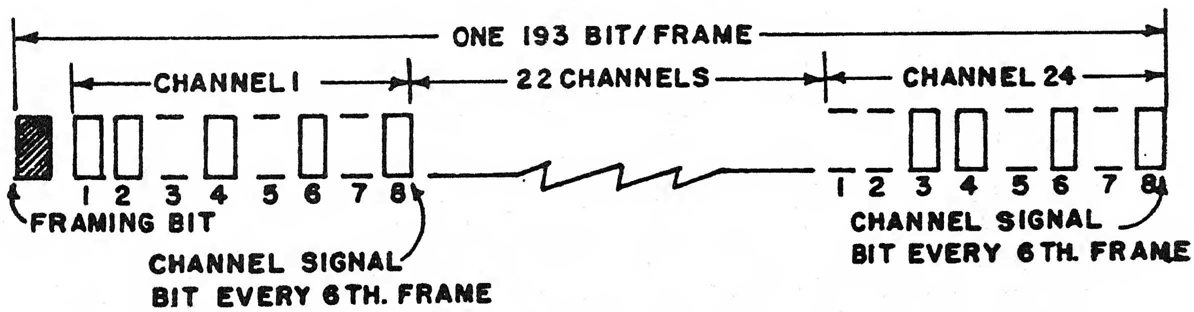
Each voice sample is encoded into a 7 bit word which makes it possible to encode 127 different voltage amplitudes. Signaling information is transmitted via an additional bit. When all 24 channels have been sampled, a framing bit is added. The total bit stream has to be 1,544,000 bits/sec (193 bits/frame X 8000 frames/sec).

Two signaling paths on the D1 are accomplished by two methods:

D1A - Bits 1 and 8 during signaling

or D1B - On the first frame bit 1 is one path and on the second frame bit 1 is the second path. On the third and fourth frames bit 1 is blank and the sequence starts over again on frames 5 and 6, etc.

D2 CHANNEL BANK FORMAT



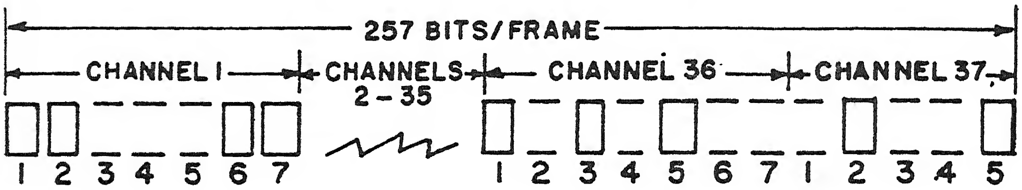
Each sample is encoded into an 8 bit word providing for up to 255 different signal levels. Signaling is accomplished by using the eighth bit for signaling every sixth frame. The total bit rate is the same as for the D1 channel bank, 1,544,000 bits/second.

Two signaling paths on the D2/D3 are accomplished by alternate use of bit 8 every sixth frame, first by one path, then the second path.

FIGURE 1

T 1 CARRIER

36 CHANNEL BANK FORMAT



Each voice channel is encoded into a 7 bit word providing for up to 127 different voltage amplitude encodings, channel 37 is a 5 bit channel, total is 257 bits/frame. There are 8000 frames scanned each second, therefore, the total bit stream is 2,056,000 bits/second (257 bits/frame X 8000 frame/second).

After the voice signals are encoded into the above format and before placing the signal on the outside plant, a 4/3 code conversion takes place to reduce the bit stream from 2,056,000 bits/second to 1,542,000 bits/second so that the regular T-1 span line can be used. The transformation from a binary to a ternary code is done according to the following chart:

Binary	Ternary Output: Positive Mode	Ternary Output: Negative Mode
0111	-++	+--
0110	00+	00-
0101	0+0	0-0
0100	0++	0--
0011	+-+	-+-
0010	-0+	-0+
0001	-+0	-+0
0000	0-+	0-+
1000	0+-	0+-
1001	+-0	+-0
1010	+0-	+0-
1011	+00	-00
1100	+0+	-0-
1101	++0	--0
1110	++-	--+
1111	+++	---

Use Pos. Mode when sum of previous digits negative

Use Neg. Mode when sum of previous digits zero or positive

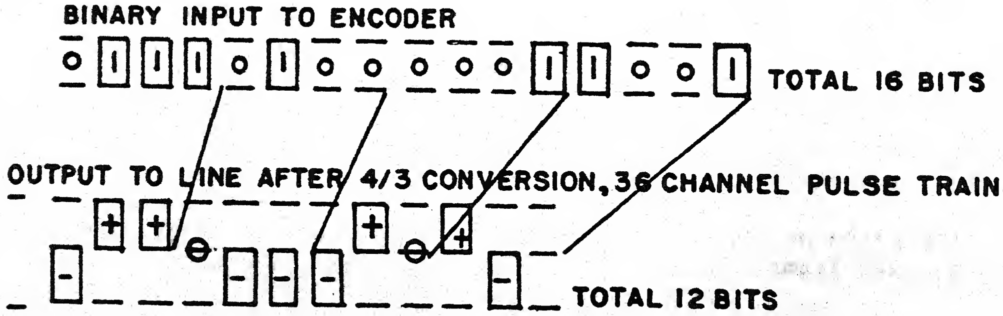


FIGURE 2

NEAR END CROSSTALK COUPLING LOSS AT 772 KHZ
FOR
CONVENTIONAL POLYETHYLENE INSULATED CABLES

Cable Size or Make Up of Groups	16ga m-s[1] dB	19ga m-s dB	22ga m-s dB	24ga m-s dB	26ga m-s dB
6 pairs or pairs in same 8- or 9-pair unit	54	55	57	58	59
12 pairs or pairs in same 12- or 13-pair unit	56	57	59	60	61
18-25 pair or pairs in same 18-25 pair unit	60	61	63	64	65
Larger sizes with pairs in adjacent 8- or					
9- or 12- or 13-pair units	65	66	68	69	70
" Pairs in nonadjacent 8- or					
9-, 12- or 13, or 25-pair units	81	82	84	85	86
" Pairs in adjacent 25-pair groups[3]					
(made up of 8 + 8 + 9 pair units)	66	67	69	70	71

NOTES:

1. m-s = MEAN minus one STANDARD DEVIATION of the mean value

2. In picking value of m-s consideration is given to pair assignments within a cable for each direction of transmission. Pick pairs in different groups if more than one group is available. If cable make up is unknown, use worse case condition.

3. Use this value if more than one unit is used for either direction of PCM transmission.

FIGURE 3

CHART FOR DETERMINING MAXIMUM SECTION LOSS IN db FOR ONE CABLE OPERATION

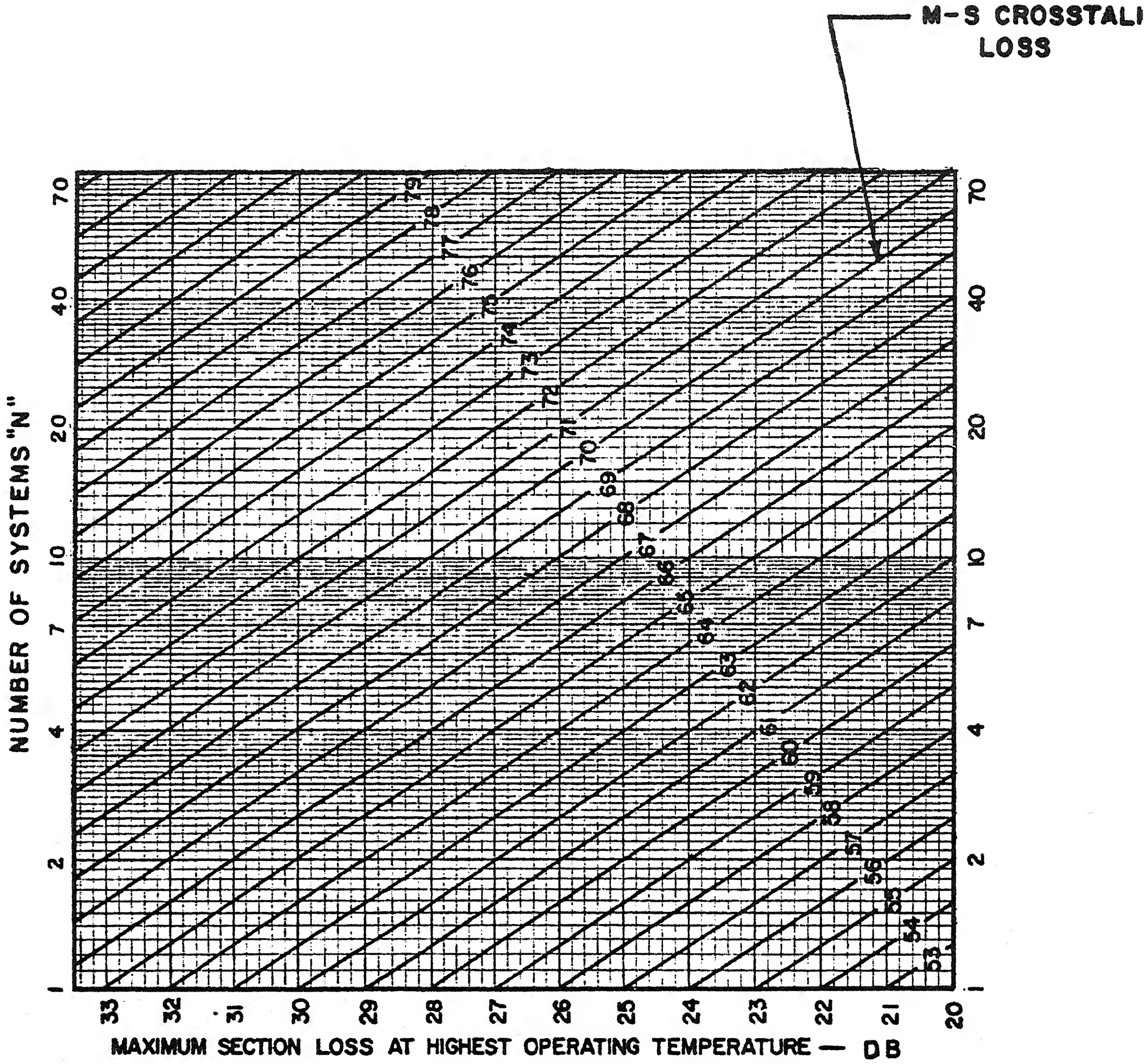


FIGURE 4
(COURTESY OF VICOM CORP.)

CABLE ATTENUATION DATA AT 772 KHZ

Cable Gauge	Type Insulation	Cap. µF/mi.	Loss @ 55°F[1] dB/KF	Loss @ 100°F dB/KF	Loss @ 140°F dB/KF
19	PIC	.066	2.78	2.92	3.05
19	PIC	.083	3.18	3.32	3.43
19	PIC/GF	.083	2.94	3.09	3.23
22	PIC	.083	4.39	4.58	4.75
22	PIC/GF	.083	3.99	4.19	4.38
24	PIC	.083	5.58	5.72	5.87
24	PIC/GF	.083	4.92	5.17	5.40
26	PIC	.083	7.48	7.65	7.82

PIC = Polyethylene Insulated Cable

GF - Grease Filled

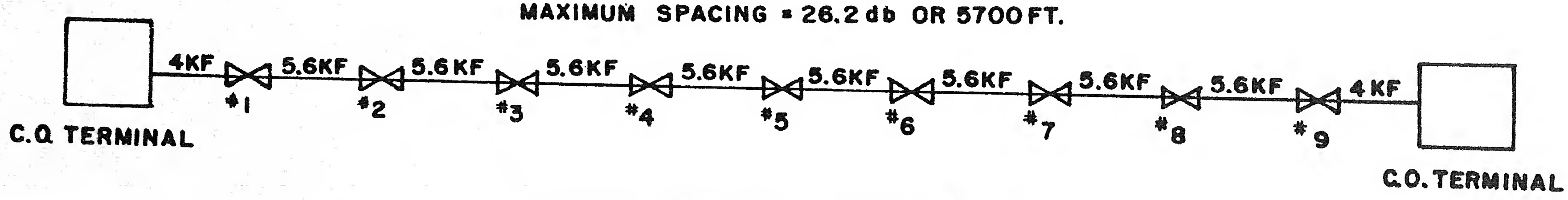
NOTE:

1. Shown for reference only. Not used in actual calculations.

FIGURE 5

CONVENTIONAL TYPE CABLE

TOTAL DISTANCE = 52.8KF
M-S = 63 db
NUMBER OF SYSTEMS = 3
MAXIMUM SPACING = 26.2 db OR 5700 FT.



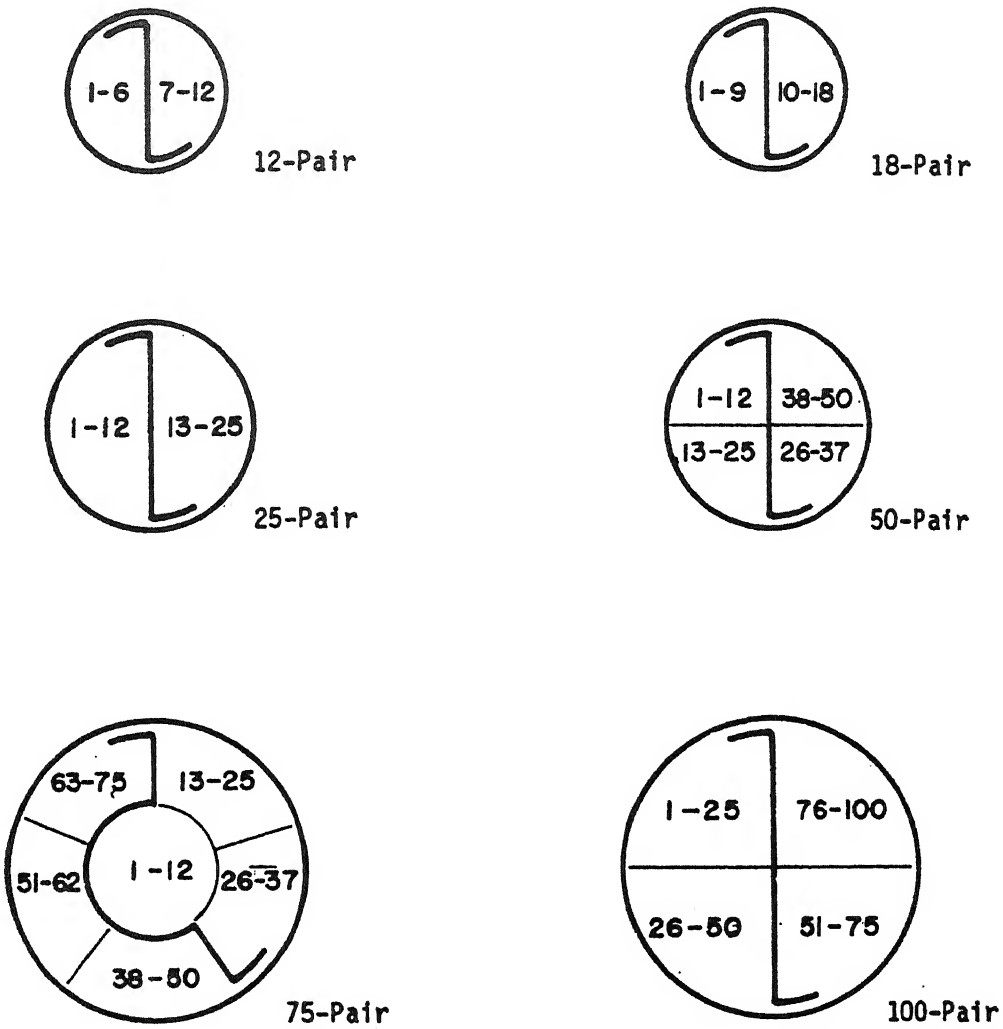
25 PAIR 22GAUGE BURIED CABLE

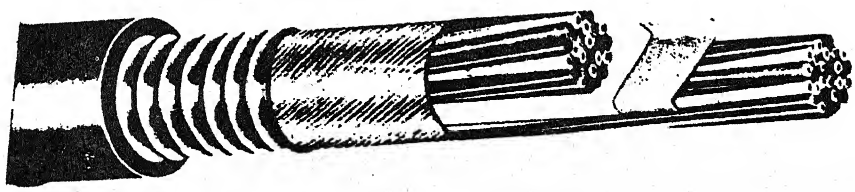
Step 1. m-s near end crosstalk loss for a 25 pair, 22 gauge PIC cable from Figure 3 is 63 dB.

Step 2. Three systems will ultimately operate over this span line, therefore, from Figure 4 the maximum section loss is 26.2 dB.

Step 3. For 22 gauge PIC cable, the maximum section length from Figure 5 is 5.7 KF (26.2 dB ÷ 4.58 dB/KF). The maximum COE section loss is 5.0 KF (23 dB ÷ 4.39 dB/KF). It is determined that for an interval of 52.8 KF, 8 repeaters fall short of the above limits. Therefore, 9 repeaters are specified as shown above. In actual practice, the location of the COE section and other repeater locations would be dictated by location of pedestals, manholes, convenient site considerations, etc. and would not necessarily result in uniform spacings as indicated in the example.

FIGURE 6





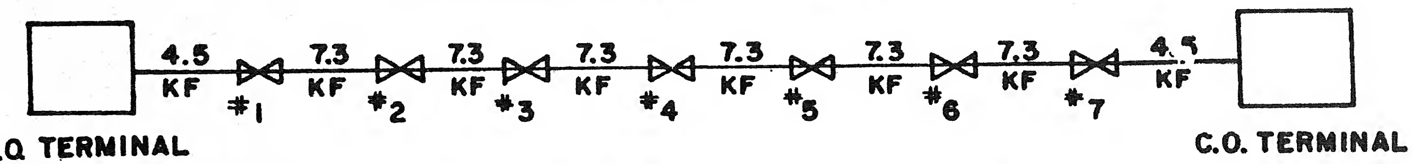
One Type of
"Compartment Type Cable"

FIGURE 7

PCM COMPARTMENT TYPE GREASE FILLED CABLE

TOTAL DISTANCE = 52.8KF

MAXIMUM SPACING = 33.5 db OR 8000 FT.



22GAUGE GREASE FILLED PIC BURIED CABLE

Step 1. Since this is compartment type grease filled cable, the maximum repeater spacing is 33.5 dB for buried plant at 100°F with the central office end section limited to 23 dB maximum.

Step 2. From Figure 5, the maximum section length is 8 KF (33.5 dB ÷ 4.19 dB/KF at 100°F).

Step 3. The maximum COE section length is 5.5 KF (23 ÷ 4.19 dB/KF).

Step 4. It is determined that for an interval 52.8 KF, 6 repeaters fall just a little bit short of the above limits. Therefore, 7 repeaters are specified as shown above. In actual practice, the location of the COE section and other repeater locations is dictated by location of pedestals, manholes, convenient site locations, etc., and would not result in uniform spacings as indicated in this example.

FIGURE 8

APPENDIX I

SOME CONSIDERATIONS IN LAYING OUT INTERROGATION AND REMOTE SPAN LOOPING SYSTEMS

1. INTERROGATION SYSTEM

1.1 The Basic Interrogation System. To facilitate trouble shooting and checking of the PCM carrier span lines, a repeater interrogation system can be incorporated into each span line. Normally, each repeater case is equipped with a narrow bandpass audio filter -- an interrogation filter. The output of the filter is bridged across the span interrogation pair. All of the repeaters in the cabinet have their interrogation winding of the regenerator output transformer connected in parallel to the input of the interrogation filter.

There are 12 codes of interrogation filters in the T1 system, thus, up to 12 repeater locations may be tied to one interrogation pair. Each filter differs only in the audio frequency which it will pass. With the basic filters, the transmit direction of the line is interrogated, making it necessary to provide means of interrogation at both end offices.

The procedure in fault location is to excite the faulty span line with a signal from a pattern generator and look for audio frequency return signals on the fault location pair. The pattern generator audio frequency is adjusted to agree with the repeater interrogation filter frequency of the nearest repeater and varied to correspond with each repeater down the line working toward the far end. The filters pass the audio signal to the fault locating pair and it is returned via the interrogation pair where it is measured. Failure to receive the audio tone of the test in progress would localize the problem to a repeater and its connecting pair. A merit test can also be conducted. By increasing the pulse density of the pattern signal, the audio tone amplitude should increase provided the PCM repeaters faithfully regenerate all pulses. A marginal repeater will make errors altering the amplitude.

1.2 The Problem of Interrogation Over a Long Span Line of More than 12 Repeaters. In the T1 span, twelve interrogation frequency filters are used in the system, the lowest frequency being 832 Hz and the highest 3017 Hz. Also, the level out of the interrogation filter into the cable pair at each repeater varies with the frequency. The lowest output has a range of about 21 to 28 dBrn at 832 Hz while the highest level output has a range of about 38 to 45 dBrn at 3017 Hz depending on the manufacturer. The sensitivity of the detector of the interrogation test set is 0 dBrn.

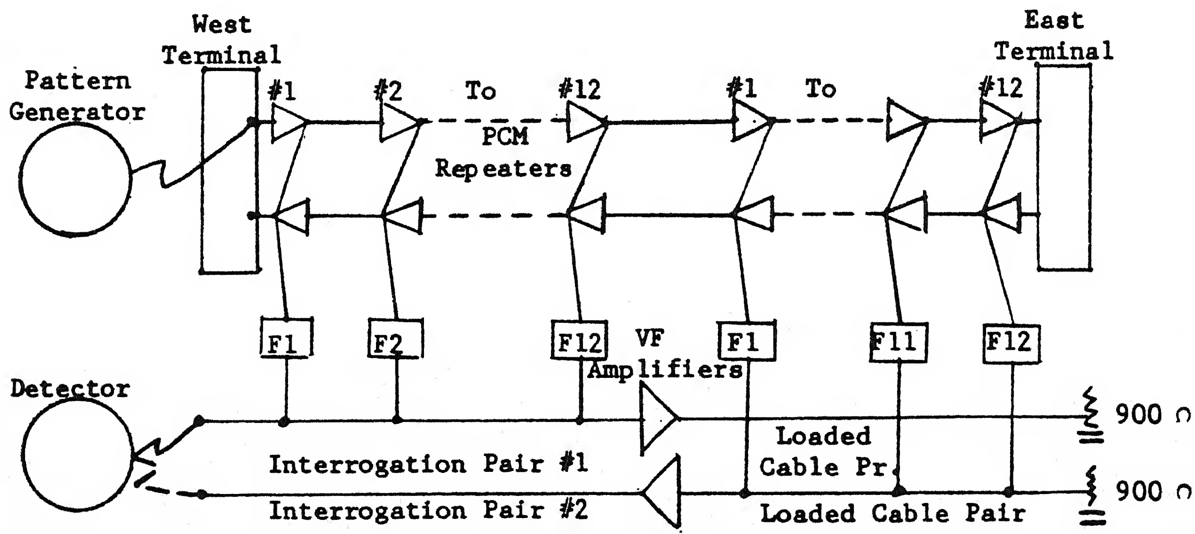
With the above outputs and detector sensitivity, the loss limits range from 21 dB or 28 dB at 832 Hz to 38 dB or 45 dB at 3017 Hz for 12 interrogation frequencies or 12 repeater locations. There may be occasion to go further than 12 repeaters in which case it is possible to interrogate

12 more repeaters using the same frequencies; however, the return path back to the central office would have to be on another cable pair. It is with the second group of 12 filters that the distance limit is explored.

In addition to the loss limit for the various frequencies, noise on the interrogation pair is probably of more concern since it is unpredictable. The noise limit in dBrnc on the cable pair can be as much as 15 dB higher than the minimum receive frequency tone level. For example, it is stated above that the sensitivity of the interrogation detector is 0 dBrn. This means that noise on the pair could be as much as 15 dBrnc, measured across tip and ring, noise metallic.

The application engineer in laying out the repeater application will assign the lower frequency interrogation filters to the housing nearest the interrogation point and the higher frequency filters to the more distant locations.

To explore the outer limits, assume 24 interrogation filters are to be employed using two interrogation pairs, Figure 9. This number will seldom be exceeded due to the limitation of feeding power to numerous repeaters from a power point. (An intermediate power supply point and interrogation point would most likely be established on the longer applications of PCM carrier.)



Assume 22 gauge cable
24 repeaters x 6 kf nominal spacing - 144 kf or 27 miles

Calculation of voice frequency non-repeatered loss:
Loss at 832 Hz, D66 loaded
= 144 kf x .149 dB/kf = 21.4 dB
Loss at 3017 Hz, D66 loaded
= 144 kf x .178 dB/kf = 25.6 dB

FIGURE 9

NOTE: For the above example, the pattern generator and detector as shown can only check the repeaters in the west to east direction. To check the repeaters in the east to west direction, the pattern generator and detector have to be located at the east terminal and the 900 Ω terminations placed at the west terminal. As shown above, the VF tones from the first 12 repeaters come back to the detector on interrogation pair No. 1. The detector has to be moved to interrogation pair No. 2 to check the second set of 12 repeaters.

From this calculation it is seen that the limit is just about 24 repeaters on 22 gauge cable using nominal 6 Kf spacing as 21 dB loss at the lower frequency is the limit. (If the manufacturer's repeater and interrogation filter level is 28 dBrn, the upper range discussed above, then the maximum limit could be as much as 28 dB.) Certainly at this long distance (27 miles or more) noise on the pair is probably the more limiting factor than loss.

Some manufacturer's instructions go into great detail on how to calculate the loss for the various frequency tones including noise measurements on the pair to assure that the above limits are not exceeded. This should be done on the longer applications.

1.3 The following recommendations are made in designing an interrogation system:

a. Load the interrogation pair beyond four repeater spans.

b. On the longer distance applications, beyond 12 repeaters, it may be necessary to use VF repeaters on the interrogation pair. One way amplifiers should be used. In the above example Figure 9, the location of the amplifiers are shown. Available gain from a one-way amplifier can be as much as 30 dB.

c. Some manufacturers, to overcome the problem of having to power repeaters in the field, have designed an optional interrogation filter which includes an amplifier with 20 dB gain or with all outputs normalized to give the same output for each filter. This is probably the simplest solution should noise or high loss or both problems exist.

d. At time of acceptance of a new installation, the tests should include proper operation of the interrogation system. A record should be made of the levels recorded from each repeater in accordance with the manufacturer's recommended test procedures when the system is operating properly. This will establish a benchmark when it is necessary to interrogate the repeaters during failure when it will be necessary to interpret data under fault conditions. It is also desirable that a routine test program be followed in order to maintain operator proficiency in using this maintenance feature.

1.4 From field experience, and by calculation, it is highly desirable to terminate the interrogation pair if it is loaded. The object

in terminating the line is to avoid high loss because of resonance condition at one or more of the interrogation frequencies. (Bridging the filters along the line has a similar effect to bridging telephone subscribers between loading points.) The termination should consist of 900 or 1000 ohms plus a capacitor (for dc blocking) of 0.5 to 2 mFd. The termination should be at both ends of each interrogation pair at the jackfield so that the near end termination is removed when the test set is plugged in. Terminations should not be on jackfields at intermediate points where the interrogation pair continues through the office.

2. REMOTE SPAN LOOPING

2.1 The arrangement of Figure 9 requires testing from both ends of the span line to interrogate repeaters in both directions of transmission. It would be desirable to be able to interrogate all the repeaters from one location. This can be accomplished by using a remote looping unit at one or both ends of the spans as shown in the following diagram.

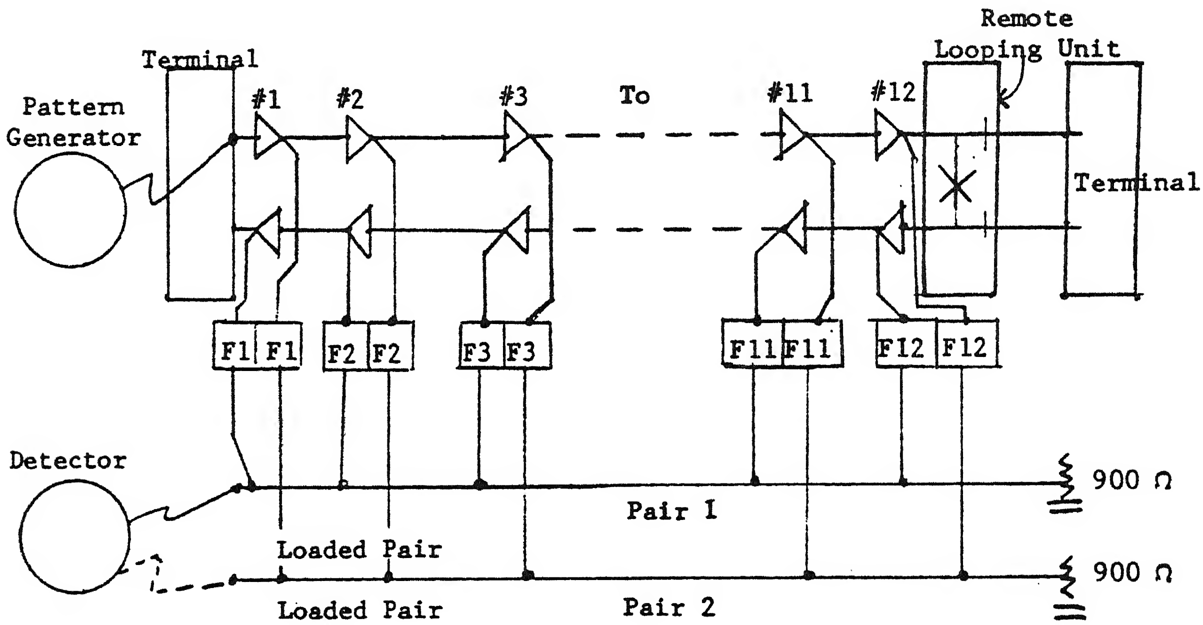


FIGURE 10

The remote looping unit is automatically activated by the "errors" introduced by the pattern generator so that by switching the detector from interrogation pair 1 to pair 2 the repeaters in the opposite direction of transmission are interrogated.

2.2 Note that in Figure 10 it takes two cable pairs for the interrogation. (It would only take one cable pair if the interrogation were performed

from both ends of the span line.) If Figure 10 was to extend over 24 repeaters like Figure 9, it would require <u>four</u> interrogation pairs.

2.3 Equipment is available that reduces the number of cable pairs required for interrogation and provides gain for interrogation cable pairs that are very long in distance. Interrogation filters can be procured that contain a 20 dB audio frequency amplifier as part of the filter unit that requires positive <u>or</u> negative voltage to power the amplifier. This doubles the number of filters from 12 to 24 that can be bridged onto one interrogation pair. By applying negative voltage on one side of the interrogation pair, one group of 12 filters becomes operative. By reversing polarity on the interrogation pair, the second group of 12 amplifiers and filters becomes operative. The configuration of Figure 9 for 24 repeaters using this equipment is shown in Figure 11.

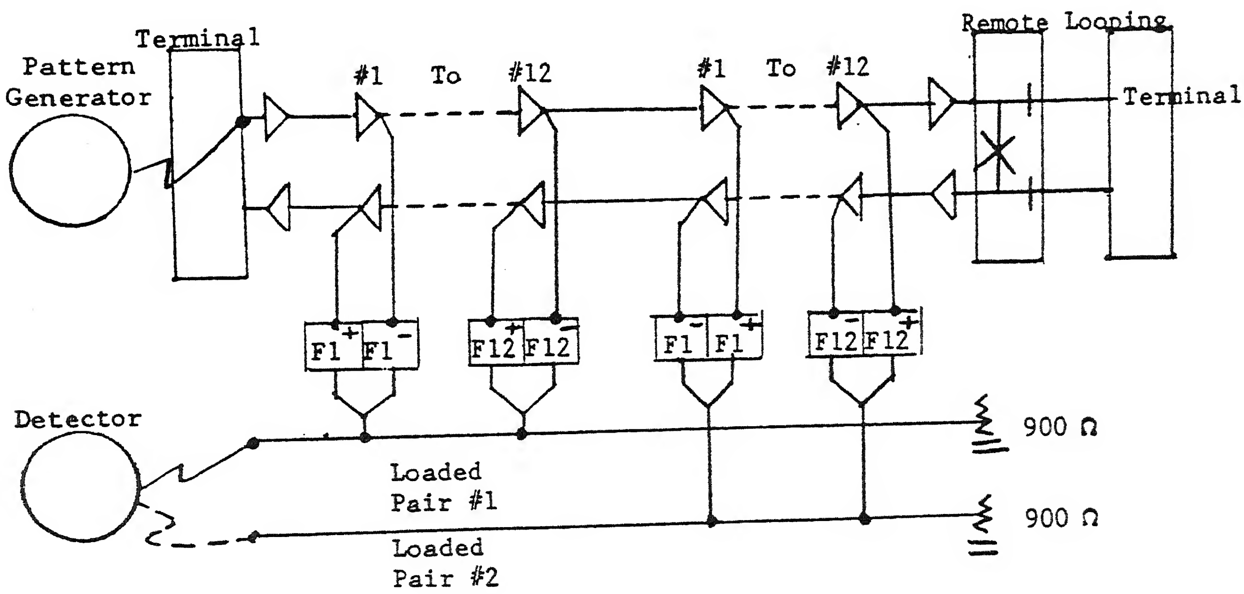


FIGURE 11

<u>NOTE</u>: The above example provides for remote span looping. With this arrangement, 24 repeater locations are interrogated from one terminal location utilizing two interrogation pairs. Note that in this example the repeater located at the terminal (the office repeater) is not connected to interrogation filter as discussed in 2.4.

The proper polarity voltage applied to each interrogation pair is done through an especially designed interrogation panel unit that provides the flexibility of patching the required polarity voltage to the proper pair and also access to the span line and interrogation cable pairs with the pattern generator and tone detector.

2.4 Note that in Figure 11, no repeater interrogation is shown for the office mounted repeaters as is shown in Figure 10. In the

4.4 With respect to span line equipment, all T1 span line facilities are the same for either the D1, D2 or D3 channel bank terminals of trunk carrier systems. It should be noted, however, that automatic span line switching systems discussed in 7.5 may not necessarily be end to end compatible as provided by various manufacturers.

4.5 REA has in effect a PE-60 Specification for Wire Line Trunk Carrier Equipment. All equipment placed on the REA List of Materials has to meet performance standards outlined in this specification regardless of whether it is of the D1, D2 or D3 type.

4.6 Data Transmission Channel Banks

4.61 An advantage of a telephone company using PCM carrier equipment in its plant is that data channel terminal banks can be operated over T1 span line facilities and provide for transmitting data ranging from slow speed to speeds as high as 512 kilobits/second. This equipment is available and can be used between two points connected by a T1 span line or several span lines interconnected.

4.62 Several types of Data Banks are available providing for slow speed data channels (teleprinters), medium speed (2,400-64,000 bit/second), and wideband data (up to 512,000 bits/second).

One type of equipment provides for either data or voice channel combinations from the same terminal. That is, data channels can be substituted for voice channels and both data and voice can be sent from the same terminal bank. An example of such an arrangement is one where 12 voice channels and one data channel at a speed of 256 kilobit/second can be transmitted over one system simultaneously.

Another type is strictly wideband data modems providing for 64, 256 or 512 kilobit/second data channels. A terminal could be arranged to contain, for example, 8 - 64 kilobit/second or 2 - 256 kilobit/second or 1 - 512 kilobit/second channels.

4.63 Another important advantage of using PCM for data is that it is unnecessary to convert computer or data outputs from digital (mark and space outputs) to analog tones for transmission within the voice frequency spectrum of the telephone network. Simple interface equipment is available for direct connection to the PCM data channel. This eliminates the need for data modems. As indicated above, this can only be done between two PCM terminals and cannot be used for interconnection to the switched telephone network. The present telephone switched network can only accommodate analog data at this time. In the future, there will exist a switched digital network at which time digital lines will be connected to each other without necessity for digital-analog interfaces.

APPENDIX II

ONE CABLE, TWO CABLE OR COMPARTMENT TYPE CABLE FOR PCM CARRIER

1. GENERAL

The design frequency for wire line application engineering is 772 kHz. If the frequency spectrum of the 1,544,000 bit/second digital bit stream of bipolar pulses is analyzed, most of the energy content is around 772 kHz. Another simplified way of looking at it is to view the bipolar pulses as plus and minus square wave pulses (2 bits) which is in effect an alternating current signal at a frequency of 772 kHz or one half the 1,544 kHz bit rate of the PCM digital bit stream.

1.1 Cable Pair Coupling at 772 kHz: Cable pair coupling, commonly referred to as "crosstalk" coupling, is of primary concern in engineering PCM systems. In digital systems where a stream of bipolar bits interfere with another due to cable pair coupling, the interference induces errors in the disturbed system and can be heard as clicks or noise in the disturbed channels. The near end coupling loss among cable pairs at repeater points is of concern. Near end and far end coupling can best be described by Figure 12 of a repeater string of two PCM systems which are operating in one cable sheath.

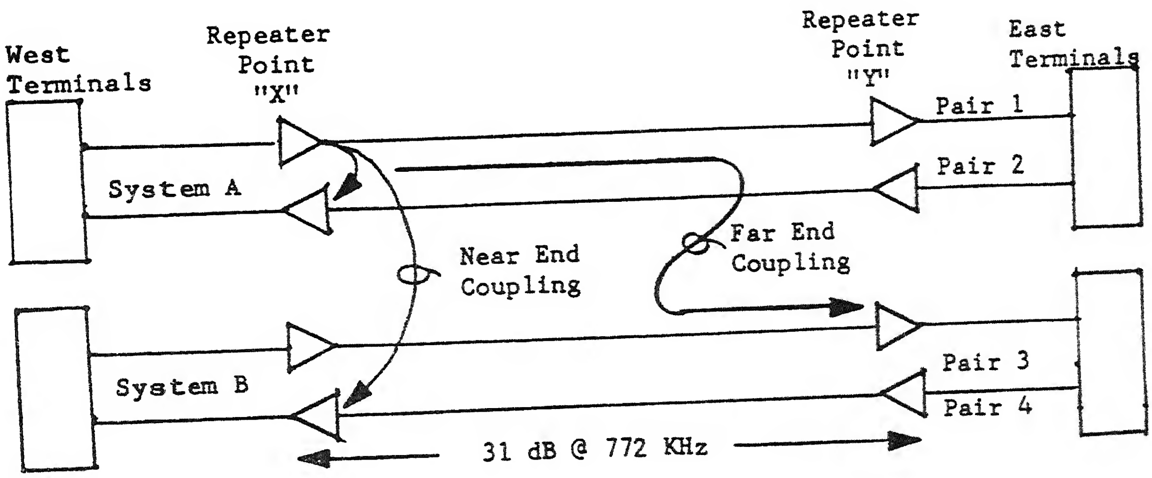


FIGURE 12

In this example the repeaters are spaced at a loss of 31 dB at 772 kHz. Far end coupling is of no concern because for a typical cable the far end equal level coupling loss might be on the order of 63 dB from pair 1 to pair 3 at 772 kHz over a repeater section. At repeater point Y, there is 63 dB of isolation between systems A and B. An amount of isolation of 63 dB is more than ample for a PCM regenerative repeater. Near end coupling is of concern in PCM systems. At repeater point X, for example, there is the high level output of system A's repeater coupling

over into the input of the repeater of system A (in the opposite direction) and system B's repeater. A typical value of near end coupling loss found in cable plant at 772 kHz might be as low as 57 dB for adjacent pairs. The reason near end coupling is more critical is that the receive level from east to west is down 31 dB at repeater point X. The coupling level from system A into the two repeaters from east to west (in both systems) is down by the near end coupling loss of 57 dB but this only affords a signal to interfering margin of 26 dB (57 dB - 31 dB assuming the output levels of all repeaters are the same). A margin of 26 dB is getting close to the point where it could interfere with the desired signal.

1.2 Two Cable or Compartment Type Cable. If two cables were used where all the repeaters in one direction are in one cable and the repeaters for the opposite direction in another cable, there would be complete isolation by direction of transmission and the near end coupling loss would no longer be critical. Since the only concern would be far end coupling loss and it is of sufficiently large magnitude to be of no concern, then the repeaters could be spaced at the maximum interval without any consideration for coupling. If two cables are available for PCM carrier, this is the preferred arrangement. Unfortunately, however, in small rural telephone systems, only one cable is usually available for both directions of transmission. Also, in rural systems it may only be necessary to provide for 1 or 2 systems on a small size cable such as 12 pair.

There are compartment type cables especially designed for PCM carrier transmission. These cables have improved near end coupling loss to eliminate the need for shorter repeater spacing. These cables cost more but may be more economical to use than one cable with repeaters spaced closer together. Appendix III discusses compartment type cables. Before proceeding too far in the application engineering of PCM carrier systems, a decision has to be made if the equipment will be operated over one cable, two cables or if compartment cables should be used. An engineering cost study is helpful in arriving at a decision.

1.3 One Cable Operation Repeater Spacing. PCM carrier systems can be operated in small sized cables such as 12, 18 and 25 pair sizes provided the repeaters are spaced close together in accordance with established rules. In this discussion, the smaller sized cables are considered. Information is available in the supplier's application manuals on how to apply PCM carrier to larger size cables where the directions of transmission can be effectively isolated from near end coupling by placing the repeaters on pairs in different binder groups or layers for the opposite direction of transmission. The factors of near end coupling loss and ultimate number of systems to operate in one cable have to be considered in determining the repeater spacing. In all application engineering manuals for PCM systems the following formula is used to determine the spacing:

$$L_d = (m-s\ -32\ -10 \log n) \frac{1}{Ft}$$

F_t = Temperature Factor

L_d = Repeater section loss in dB at highest operating temperature

m = Mean near end coupling loss in dB

s = Standard deviation of "m"

n = Number of PCM systems in the cable

The terms "m" and "s" are described for a better understanding. The near end coupling properties of wire pairs in cable are determined by measuring the coupling loss of all pair combinations. This can be a lot of measurements -- for 12 pairs, 66 combinations; 18 pairs, 153 combinations; 25 pairs, 300 combinations, etc. In this discussion, cables of 25 pairs and smaller are considered as one group. The mean (arithmetic average) near end crosstalk coupling of all the individual combinations is the value "m". The standard deviation of this distribution is calculated by standard statistical methods. One standard deviation, "s" (sigma), is that range from the mean value of a "normal" distribution which encompasses 34 percent of the observations of the statistical sample. It is a standard statistical tool for defining a variance from a mean value. Therefore, if one standard deviation "s" is subtracted from the mean value (m-s) this means that 16 percent of the pair combinations have lower (poorer) near end coupling values than the m-s value.

Normal Distribution of Crosstalk Coupling Values of Individual Pair Combinations

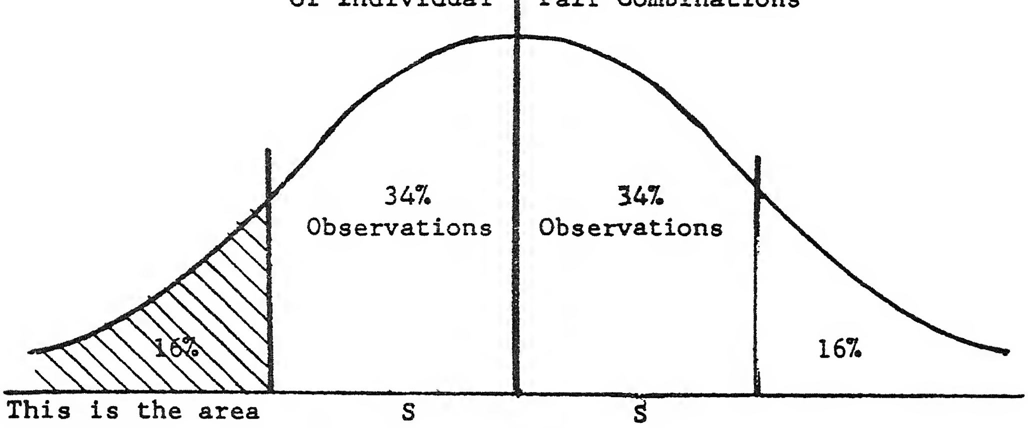


FIGURE 13

It would be unlikely that cable pairs from reel after reel of cable would be picked within the 16 percent of the pairs which have poorer near end coupling loss than the m-s value. Even at that there

is a safety factor provided for in the number values of the above formula. Near end crosstalk data shown in Figure 3 is used by carrier application engineers to obtain values of m-s for various types of cables, gauges and configurations.

1.31 The following example is used to analyze this formula:

It is planned to place three PCM systems in one 25 pair 22 gauge plastic cable.

Forgetting the $\frac{1}{Ft}$ factor of the formula since charts and tables are readily available for temperature correction, the repeater spacing is:

$$L_d = m\text{-}s - 32 - 10 \log n$$

$$m\text{-}s = 63 \text{ dB from Figure 3}$$

$$n = 3$$

$$L_d = 63 - 32 - 10 \log 3$$

$$= 63 - 32 - 4.77$$

$$= 26.2 \text{ dB}$$

As can be seen by this formula, the factor "10 log n" considers the number of systems transmitting interference into the disturbed receiver and in this example the spacing is reduced 4.77 dB because of the three systems operating together in the same cable.

1.4 In 1968, REA with the cooperation of several cable manufacturers, measured near end coupling losses of small size cables as shown in Figure 14 to verify if REA specification cable possessed the near end coupling loss for 6, 12, 18 and 25 pair cables as stated in carrier manufacturer's application manuals. REA cables met these requirements and, therefore, the data in Figure 3 also applies to REA specification cables.

MEASUREMENT DATA OF NEAR END COUPLING LOSS FOR 66 REELS OF REA SPECIFICATION CABLES

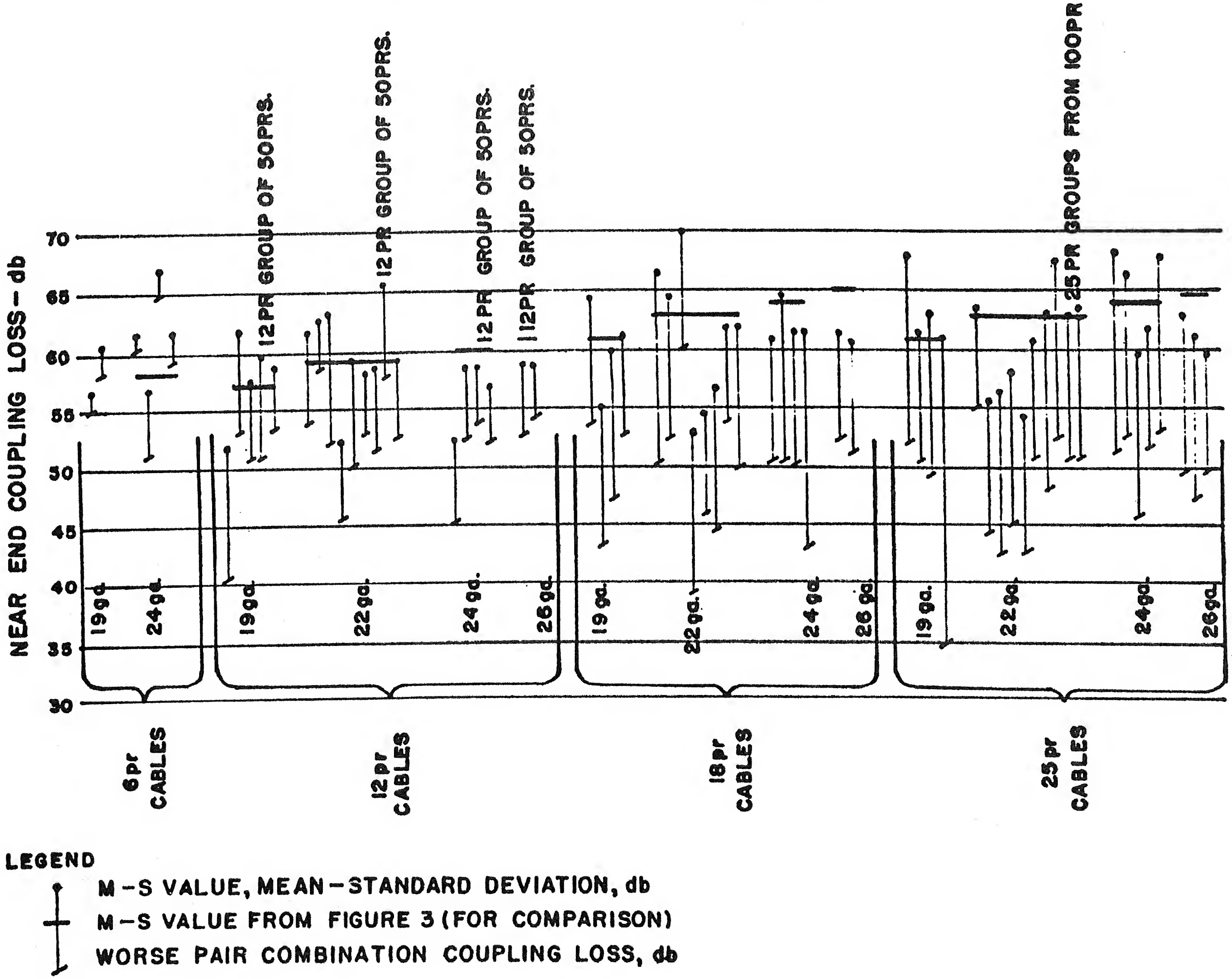


FIGURE 14

APPENDIX III

COMPARTMENT TYPE CABLE FOR PCM CARRIER

1. GENERAL

An improvement in the near end coupling losses of paired cables has been achieved by the use of a special shielding technique which divides the pairs within the cable sheath into two compartments. What is significant is that the increased cost is only in the order of ten percent for which the reduction of near end coupling loss means less repeaters. Figure 15 shows the improvement in the m-s value crosstalk coupling loss of one type of compartmented cable now commonly used.

1.1 The following example shows that crosstalk loss, for all practical purposes, has been eliminated as a factor in determining repeater spacing:

It is considered placing three PCM systems in our 25 pair, compartment type cables, the same example as in Appendix II.

L_d = m-s -32 -10 log n

m-s = 80 dB from Figure 15

n = 3

L_d = 80 -32 -4.77

L_d = 43.2 dB

A spacing of 43.2 dB exceeds the maximum spacing capability of PCM repeaters (33.5 dB) so it is seen that near end crosstalk is no longer controlling.

1.2 With compartment type cable it is possible to make 100 percent use of cable pairs for PCM carrier. The following example illustrates this for a 25 pair compartment type cable. Probably no more than 10 systems including spare span lines (20 pair) would ever be installed in a 25 pair cable leaving a few pairs for interrogation, order wires, etc.

L_d = m-s -32 -10 log n

m-s = 80 from Figure 15

n = 10 systems

L_d = 80 -32 -10 log 10

= 80 -32 -10

= 38 dB

A spacing of 38 dB still exceeds the maximum spacing capability of PCM repeaters (33.5 dB). Near end crosstalk coupling limitation is not controlling.

1.3 In Appendix II, the terms m-s, mean minus one standard deviation coupling loss, are discussed. To show an example of this discussion and to reveal the benefits of the compartment type cables, reference is made to Figure 16. This is a display of the near end coupling losses of an 18 pair compartment cable for PCM carrier of the type shown in Figure 7. All 153 pair combinations are shown. The "X" readings are the near end coupling losses of the pair combinations within each compartment. The "O" readings are the near end coupling losses of the pair combinations from one compartment to the other. The advantage of the shielding effect from one compartment to the other is clearly noted. Note the two distinct groupings outlined by the dotted line. The data of each grouping is analyzed and the m-s, "mean minus one standard deviation," computation is made as follows:

$\overline{X}$ = arithmetic mean of "n" observations, each pair combination near end crosstalk reading in dB is one value of X.

s = standard deviation = $\sqrt{\frac{X^2}{N} - \overline{X}^2}$

Where X^2 = sum of the squares of each individual value of X
N = 81 readings (the pair combinations of pairs 1 through 9 into pairs 10 through 18 which are divided by a shield into two groups).

The m-s value for the shielded pair combinations computes to 79.1 dB. The m-s value for the non-shielded pair combination computes to 58.7 dB.

Near End "M-S" Loss
of Core Separated Cable for PCM Carrier

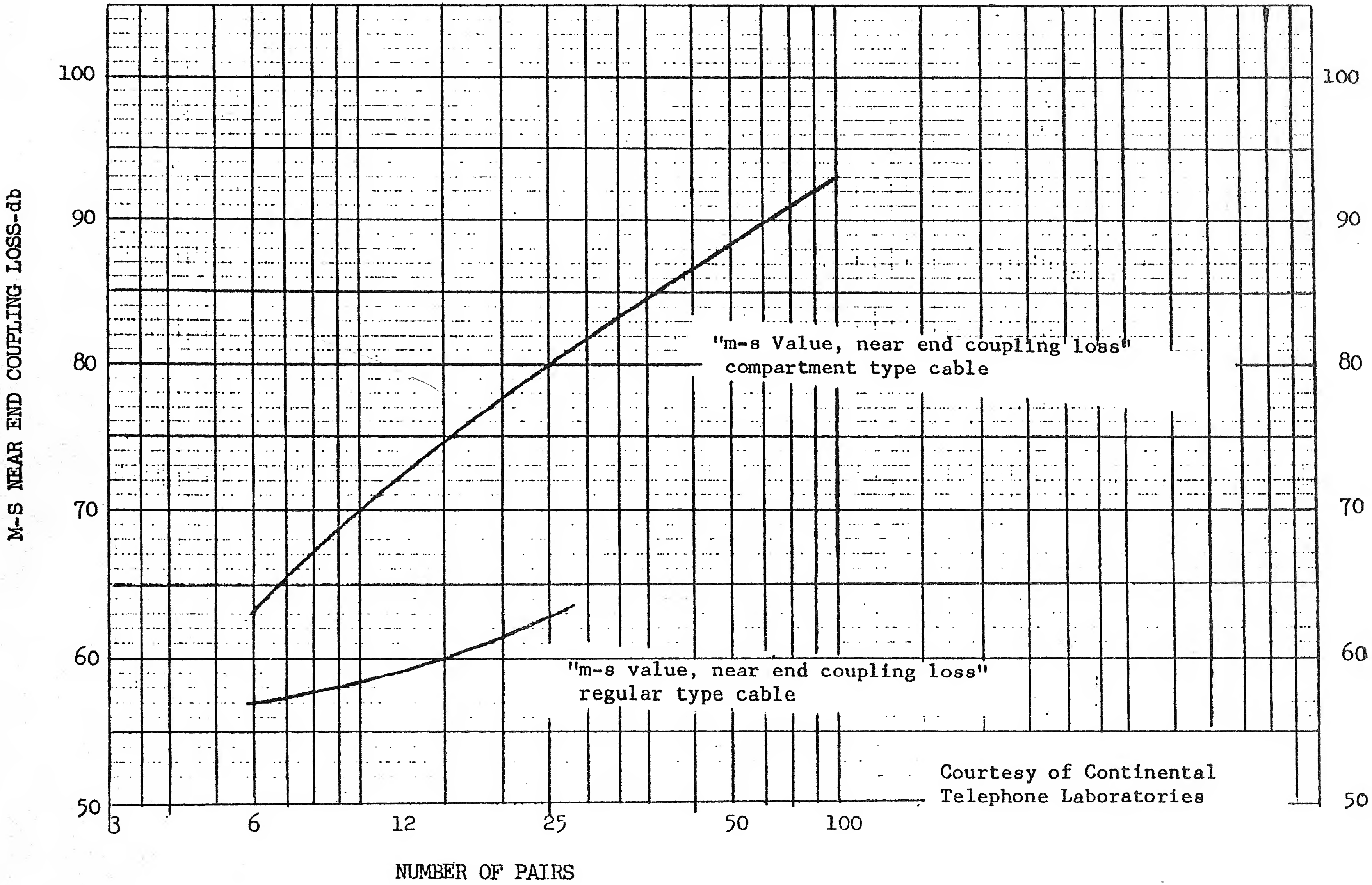


Figure 15

COMPARTMENT TYPE CABLE COUPLING LOSS

18 PAIR – 22 GAGE PIC CABLE
.083 μf/MILE MUTUAL CAPACITANCE

M-S = 86.1 – 7.0 = 79.1 db OF THE PAIR COMBINATIONS SEPARATED BY THE INNER SHIELD.

M-S = 67.5 – 8.8 = 58.7 db OF THE PAIR COMBINATIONS WHICH ARE NON-SHIELDED FROM EACH OTHER.

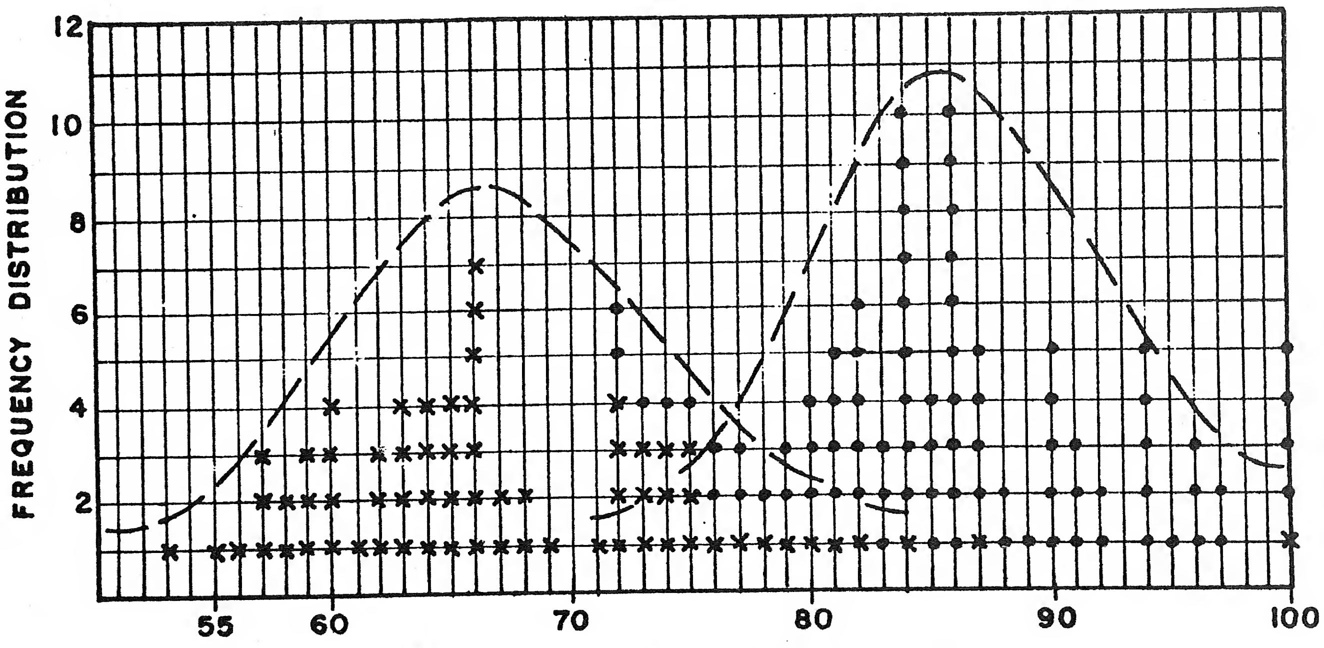


FIGURE 16